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SEAMLESS SIMULATION LITERATURE SURVEY

Stephen Downes-Martin

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SEAMLESS SIMULATION LITERATURE SURVEY

Stephen Downes-Martin

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ABSTRACT

This report is a summary review of people and organizations developing ideas for Seamless Simulation. Seamless Simulation is defined as the linking of heterogeneous systems on a simulation network. The current Distributed Interactive Simulation (DIS) technology supports a network of hundreds of vehicles at the battalion tactical level. Systems such as computer generated forces interact at the vehicle level via a network protocol, and current efforts to produce a DIS network standard are aimed at homogeneous objects (vehicle simulators) implemented in a heterogeneous manner (by different manufacturers). Seamless Simulation seeks to extend this technology to heterogeneous objects (vehicle simulators and unit level wargames, for example). Recommendations are: strengthen DoD support of Seamless Simulation projects; extend the current DARPA/PMTRADE (Program Manager for Training Devices) sponsored workshop on DoD/Industry Standards for the Interoperability of Defense Simulations from the vehicle level to the general defense simulation and system level; allow the Seamless Simulation effort to take advantage of modern software engineering and become explicitly object oriented; integrate the DoD effort with the business Object Management Group Architecture effort.

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1.0 EXECUTIVE SUMMARY

1.1 PURPOSE OF THE DOCUMENT

This report provides a summary literature review of people and organizations developing ideas for Seamless Simulation, where Seamless Simulation is defined as the linking of heterogeneous systems on a simulation network. The current Distributed Interactive Simulation (DIS) technology supports a network of hundreds of vehicles at the battalion tactical level. Systems such as computer generated forces interact at the vehicle level via a network protocol. Current efforts to produce a DIS network standard are aimed at homogeneous objects (vehicle simulators) that are implemented in a heterogeneous manner (i.e., by different manufacturers). Seamless Simulation seeks to extend this technology to heterogeneous objects (vehicle simulators and unit level wargames, for example). The purpose of this report is to provide a survey of public domain ideas, analyses, systems, and proposals to measure and encourage new ideas in Seamless Simulation, and to assist in avoiding redundant effort.

The literature survey is necessarily brief, and cannot cover the topic completely. In addition, new work is going on all the time, so this survey will require updating. Projects such as CRONUS or CASES, for example, were excluded from this survey due to lack of time.

1.2 BACKGROUND ON SEAMLESS SIMULATION

1.2.1 Distributed Interactive Simulation in the 1980s

SIMNET (Simulated Networking) was DARPA's distributed simulation program from 1983 to 1990, consisting of distributed combined arms tactical team trainer prototypes. It forms the basis of the current DIS technology. The DIS technology supports a network of hundreds of vehicles at the battalion tactical level (see Figure 1) [Downes-Martin and Saffi, 1987], distributed over the continental United States, consisting of a mix of fully manned simulators, analysis tools (see Figure 1) [Garvey and Monday,

1989; GTRI, 1990], and Semi-Automated Forces (see Figure 2) [Brooks et al., 1989; Downes-Martin, 1989b]. Systems such as computer generated forces interact at the vehicle level via a network protocol (see Figure 2) [Downes-Martin, 1989b], and current efforts to produce a DIS network standard [IST, 1989, 1990, 1991 inclusive] are aimed at homogeneous functionality objects (vehicles) which are implemented in a heterogeneous manner (by different manufacturers).

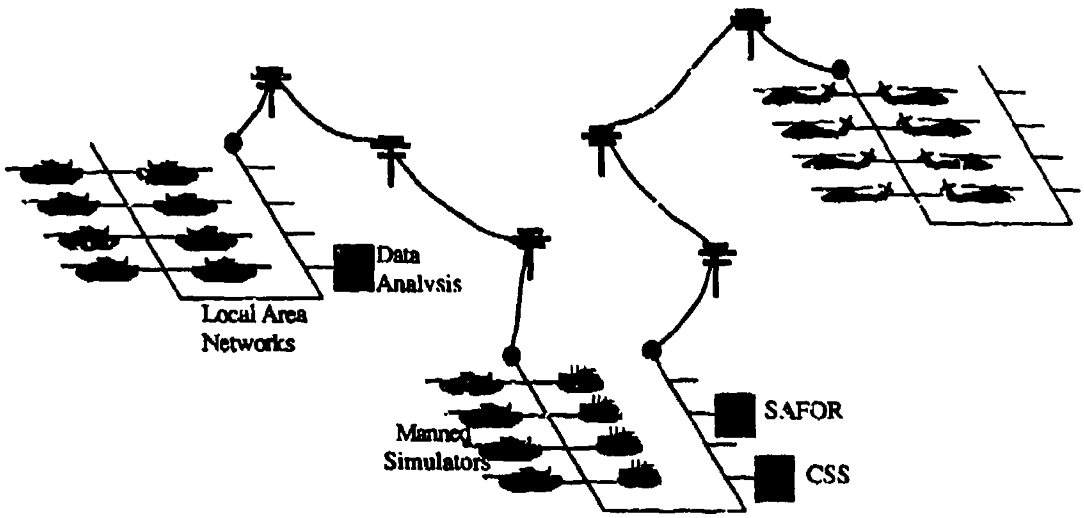

Figure 1: SIMNET Distributed Interactive Simulation Architecture. The baseline DIS architecture is provided by the DARPA SIMNET (SIMulator NETworking) project [Garvey and Monday, 1989; GTRI, 1990]. This links manned vehicle simulators, data analysis tools, Combat Service Support simulators, and Semi-Automated Forces by local and long-haul networks. All interaction is at the vehicle level via a set of vehicle level Protocol Data Units. Different vehicle types by the same manufacturer (Bolt Beranek and Newman) are networked, thus we have a homogeneous functionality (vehicles) homogeneous implementation (same manufacturer) system.

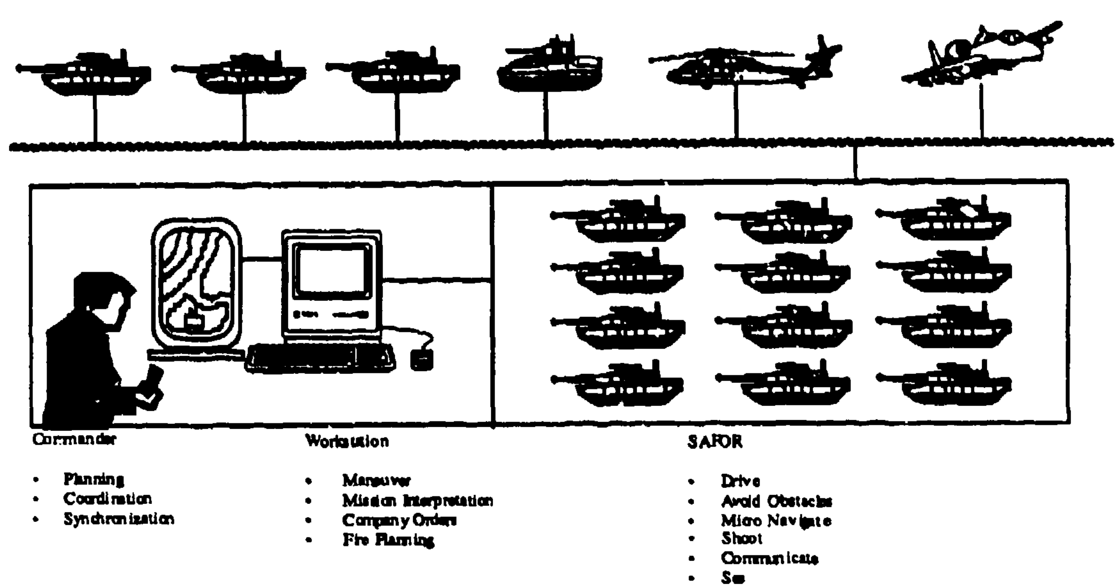

Figure 2: Semi-Automated Forces Architecture. Although the user-interface to the Semi-Automated Forces is at the Unit level, the SAFOR interact with SIMNET at the vehicle level via the same vehicle Protocol Data Units as do manned vehicle simulators [Downes-Martin, 1989b]. What we see here is unit level simulation at vehicle level resolution interacting with manned vehicle simulators, a first step towards Seamless Simulation.

The SIMNET project is essentially over. The "center of mass" of SIMNET is now perceived by DARPA to have shifted away from *Advanced* Research and Development and into the Research and Development world; however, certain portions of SIMNET, most notably the Semi-Automated Forces, remain Advanced Research and Development. Thus SIMNET has been transferred to PMTRADE (Program Manager for Training Devices), under the PMTRADE umbrella initiative Advanced Distributed Simulation Technology (ADST).

1.2.2 Distributed Interactive Simulation in the 1990s

The failure of some National Guard Combat Units to deploy to the Gulf War has highlighted the training problems of the armed forces of the United States. As a result, both DARPA and PMTRADE have recently announced major initiatives in distributed simulation applied to team training. These initiatives will be in addition to those already seen as extensions and expansions of the SIMNET distributed simulation technology

[Pasha, 1991a, 1991b]. PMTRADE will extend the state of the art in DIS under their Battlefield Distributed Simulation--Developmental (BDS-D) program, while DARPA continues its interest in the area under the umbrella initiative Advanced Warfighting Simulation (AWS). These two umbrella initiatives overlap each other considerably, although it is PMTRADE who is responsible for producing training products based on distributed simulation [such as CCTT (Command Combat Tactical Training)].

For these reasons, DARPA and PMTRADE are interested, along with the Services, in expanding the current DIS technology along a number of dimensions (see Figure 3) [McBride, 1990]. These dimensions include: vertical expansion from the current tactical battalion size battles of hundreds of vehicles to joint/theater with tens of thousands of vehicles; horizontal expansion to include all battlefield functional areas [such as C^3I (Command, Control, Communications and Intelligence), IEW (Intelligence and Electronic Warfare), Planning, etc.]; and application-oriented expansion in which the previous two expansions are implemented by networking vehicle simulators, wargames, computer generated forces, and operational equipment. It is interesting to note that the recent DARPA conference on 73 Easting [DARPA, 1991b] has resulted in the requirement to integrate historical data tracks with interactive (and possibly stochastic) simulations.

This expansion requires the integration on a network of objects that are not only heterogeneous in implementation but are also heterogeneous in military function. For example, aggregated unit level objects produced by a wargame must be able to interact with manned vehicle simulators (see Figure 4) [McBride, 1990]. All simulation objects produced by the heterogeneous functionality systems on the net must be able to interact with each other in a consistent and realistic manner. This requires that each object is presented with an environment that is supported by the computer system that generates that object. Some of the major technical challenges that arise as a result of the proposed expansion of the DIS technology are:

- **Vertical Expansion.** The current distributed simulation technology supports battles at the several hundred vehicle level, Regiment+ versus Battalion+, with a mix of manned simulators and semi-automated forces. The goal is to provide a simulated theater/joint command level battlefield at the vehicle level of resolution, in which tens of thousands of platforms are simulated by a mix of manned simulators and semi-automated forces. It is expected that the majority of these vehicles will be semi-automated. Vertical expansion assumes joint Service participation, and international participation.

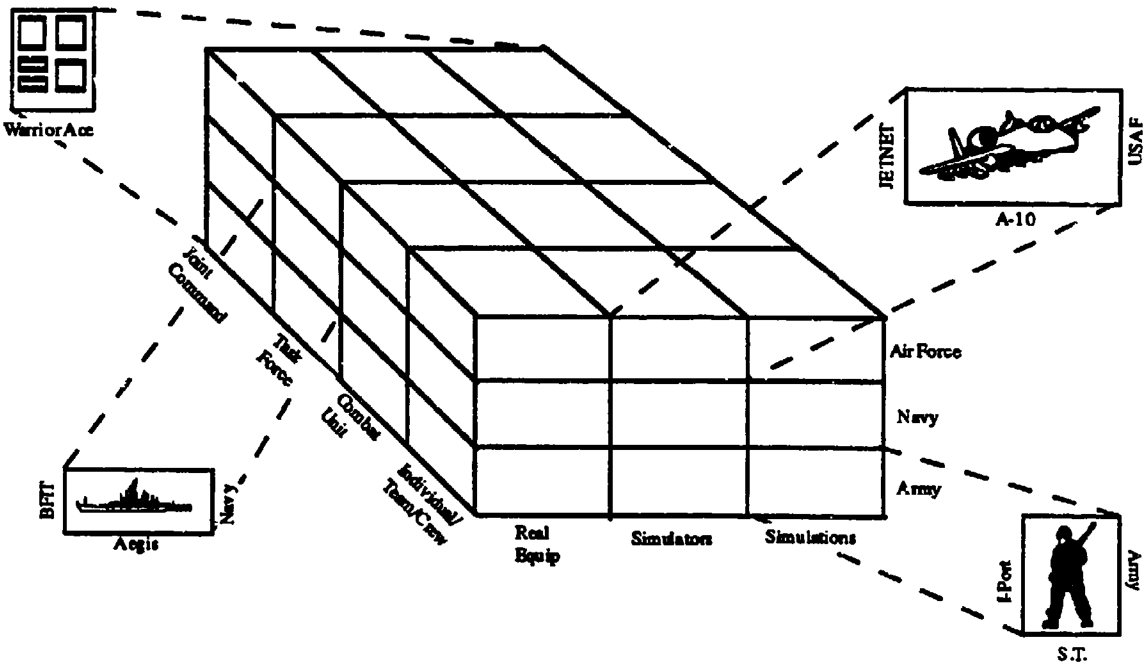

Figure 3: DARPA/PMTRADE Seamless Simulation. DARPA and PMTRADE wish to extend the Distributed Interactive Simulation (as exemplified by SIMNET) along a number of interacting dimensions [McBride, 1990]. These include vertical expansion to a full Joint/Theater sized simulated battlefield and the corresponding horizontal expansion to include all battlefield functional areas (such as electronic warfare and intelligence for example). To support this expansion DARPA and PMTRADE propose that extant and future systems of all functionality be linked into a single global synthetic environment. These systems include manned simulators, computer-driven Semi-Automated Forces, unit level wargames, and real operational equipment.

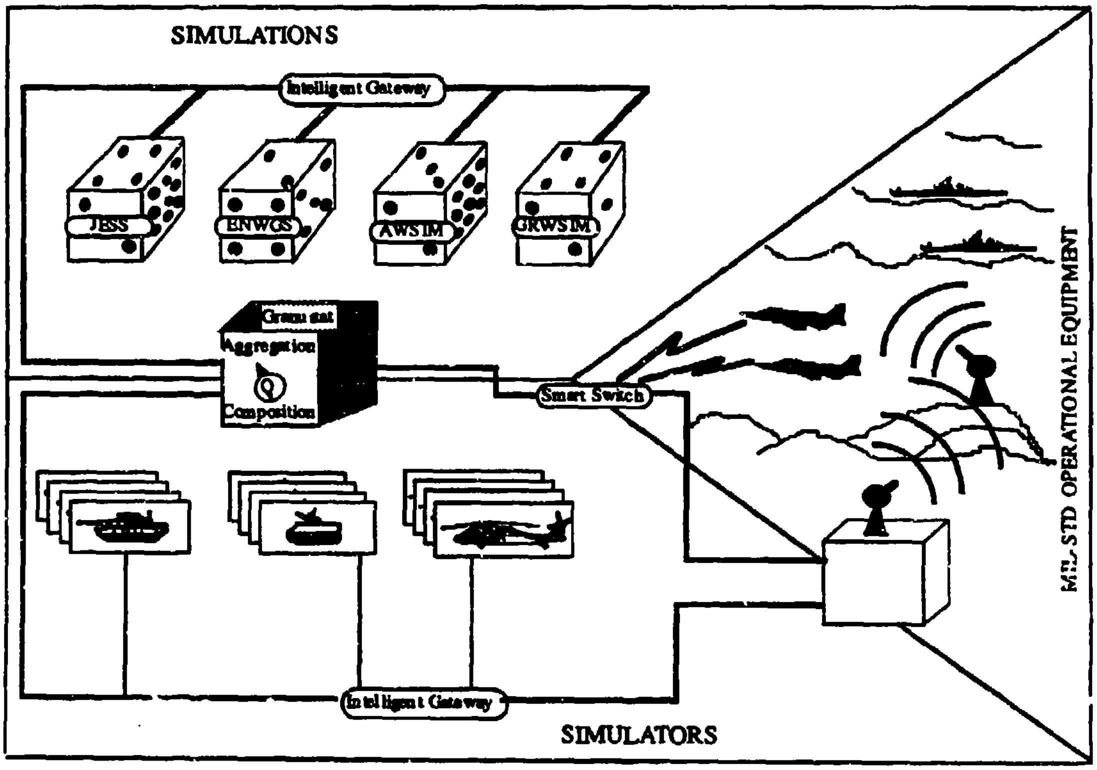

Figure 4: DARPA Heterogeneous Functionality Integration. Seamless Simulation implies the integration of heterogeneous functionality systems, systems that represent different kinds of object or application [McBride, 1990]. Peculiar problems arise when attempting to integrate high update rate deterministic manned vehicle simulators with low update rate stochastic wargames, or extremely high resolution operational equipment with medium to low fidelity simulation systems.

- **Horizontal Expansion.** Along with the vertical expansion, the full range of battlefield functional areas must be included. The current SIMNET technology is essentially direct fire and maneuver for ground and aviation, with crude artillery, logistics, and maintenance. When theater level warfare is considered, the full range of battlefield functional areas must be included. In fact, as the simulation expands vertically, functions other than fire and maneuver dominate, such as C^3I, while at the battalion level the reverse is true.

- **Five-Figure Vehicle Battlefield.** As the level of command rises, the potential number of platforms that must be simulated rises into the tens of thousands. Both DARPA and PMTRADE require that the simulated battlefield be observable at the vehicle level of resolution at arbitrary times and places. This must be done without prohibitive hardware or personnel costs.

- **Computer Generated Forces.** On a simulated battlefield of tens of thousands of vehicles, most of those vehicles are going to be semi-automated. In addition, the C^2 distance between the senior level of command and the vehicle level of combat execution increases beyond the normal "look down two, command down one." The Semi-Automated Forces commander cannot effectively supervise his subordinates below two levels down, and thus the Semi-Automated Forces must become autonomous and smart at the lower levels of command. DARPA refers to this whole area as Behavioral Representations for Computer Driven (or Semi-Automated) Forces. Alternatively, techniques might be developed to staff the command hierarchy in a sparse fashion, but this increases the personnel costs. Current semi-automated forces design principles specify that the only personnel are at the most senior level of semi-automated forces present. This means that any forces more than two levels down must be capable of intelligent autonomous behavior. A design change to insert commanders in a sparse fashion throughout the command hierarchy fits in with the Battle Command Integration Program [BCTP (Battle Command Training Program) at Fort Leavenworth] plans for integrating FAMSIM (Family of Simulations), but is in conflict with frequent military statements that the Semi-Automated Forces must be capable of being run by a single level of command.

- **Seamless Simulation.** This generalizes interconnected vehicle simulations to interconnected defense simulations. The goal is to provide a simulated battlefield at theater level in which aggregate wargames (both current and future), vehicle simulators, actual field equipment (both combat vehicles and C^3I assets), individual soldier "virtual reality" ports, and semi-automated forces all interact in such a way that the seams between the technologies are hidden from the participants. This includes interconnecting real armored vehicles on the National Training Center with manned vehicle simulators

[Pasha, 1991a], and integrating the individual soldier on the simulated battlefield as though he were on foot and operating battlefield equipment [Gorman, 1990].

The basic technical challenge here is to provide an interface between simulations of heterogeneous granularity such that each simulation or piece of equipment sees a rational world according to its expectations, and that the various worlds seen by all the participants are consistent with each other both in time and space. Aggregation and de-aggregation of simulation entities must be carried out dynamically, and the distributed simulation network protocol must be extended to take account of the new non-vehicle objects on the net.

The Industry/DoD Standards for Interoperability of Defense Simulations Workshop, funded by DARPA and PMTRADE, is administrated by the Institute for Simulation and Training at the University of Central Florida (UCF/IST). The goal is to develop standards that will allow vendors to internet their own vehicle simulators to those from any other vendor without knowledge of the internals of their competitors' machines. The effort includes working groups to handle human-machine interfaces, network protocols, and terrain databases. This effort has so far restricted itself to interconnecting vehicles only, but will shortly address interconnecting wargames with vehicles. A number of draft standards and position papers have been published [IST, 1989, 1990, 1991 inclusive; Pope, 1989].

1.3 OVERVIEW OF SEAMLESS SIMULATION ISSUES

Seamless Simulation involves the integration into a single synthetic environment of many distributed objects with heterogeneous functionality and heterogeneous implementation. Some of the issues are common to those involved in integrating vehicle level simulations, such as terrain data bases, communications architectures, and interfaces. However, the current DARPA/PMTRADE sponsored workshop on DoD/Industry Standards for the Interoperability of Defense Simulations is already handling these in great detail. This detail is firmly based on the assumption of homogeneous functionality systems, i.e., interaction of vehicles at the vehicle level of resolution. The overview of Seamless Simulation issues provided here is an attempt to review from literature a general set of issues that cover heterogeneous functionality systems. These issues should subsume those for the vehicle level. It should be noted, however, that the issues discussed here are drawn from a variety of sources, and do not necessarily constitute a systematic theory of Seamless Simulation. The overview provided here is for the purpose of providing a

background for the literature review. An attempt is made in this report to place these issues in a broad framework; a theory of Seamless Simulation will be attempted in a later report.

The fundamental goal of Seamless Simulation is to provide an architecture that links heterogeneous functionality-heterogeneous implementation systems into a consistent synthetic environment. This goal breaks down into two subgoals, both of which must be considered:

- **Synthetic Environment Construction.** The Seamless Simulation will make use of a large number of heterogeneous systems to create a synthetic environment. Selection must be made before run time of which applications, processes, databases, and user interfaces (and which versions) are going to be used. A large number of general architecture issues are relevant, including the construction of new applications before run time by integrating components from multiple applications across the network.
- **Synthetic Environment Dynamics.** The Seamless Simulation during run time must maintain a global internal consistency and satisfy user criteria of military reality. Application interactivity at the conceptual and dynamic level are the fundamental issues applicable to this subgoal.

These subgoals in turn generate three classes of requirements:

- **Simulation Truth.** There exists a simulated ground truth that is the same no matter which system is used to interface to the Seamless Simulation. Each interlinked system may or may not deal with uncertainty, intelligence, or the fog of war by suitably filtering this ground truth in some way.
- **Conceptual Consistency.** The Seamless Simulation must be globally consistent in conceptual terms. Each interlinked system must be able to interact with the Seamless Simulation using its own conceptual structures. For example, a vehicle simulation interacting with a unit level simulation must be able to interact with the units in terms of vehicles. Conversely, the unit simulation must be able to interact with the vehicle simulation in terms of units. This means that computer driven units or vehicles must interact with humans in a credibly realistic fashion.
- **Temporal Consistency.** The Seamless Simulation must be globally consistent in temporal terms [Weatherley et al., 1991]. Each interlinked system must interact with the Seamless Simulation in a timely and causal fashion, maintaining temporal logic. For example, a fast update-rate vehicle simulation interacting with a slow update-rate unit simulation must perceive the Seamless Simulation as containing fast update-rate vehicles, and those (unit generated) vehicles must respond to the vehicle simulation at the same update rate.

These requirements in turn generate four major technical dimensions to the problem of generating a Seamless Simulation technology:

- **System Architecture.** System architecture determines the mechanics of how the distributed system is put together, including the communications between each interlinked system. Hardware and software issues are dealt with here [Weatherley et al., 1991].
- **Data Management.** "Data Management is responsible for the rules by which data can be changed, and the interpretation of data values." Conceptual consistency issues are dealt with here, including aggregation and deaggregation of units, and terrain consistency [Weatherley et al., 1991].
- **Human Machine Interaction.** Human Machine Interaction covers issues such as how simulation agents are to be built that simulate human performance to an acceptable degree of realism, the knowledge bases required to support the simulation of human behavior, and the cognitive models [Downes-Martin, 1989a; Deutsch, 1989; Abrett et al., 1990a, 1990b].
- **Time Management.** Time management deals with the temporal consistency issues, timeliness and temporal logic, or causality, of the Seamless Simulation. This includes the different time rates at which, for example, a unit simulation runs compared with a vehicle simulation [Weatherley et al., 1991].

These dimensions in turn break down into component issues, and a certain amount of flexibility occurs in determining to which dimension each component issue belongs. It should be noted that the System Architecture and Data Management dimensions are similar to those raised by the Object Management Group [Soley, 1990] in their architecture for integrating heterogeneous business applications across networks. Time Management arises in Seamless Simulation due to the competitive nature of combat and the resultant requirement for simultaneity and temporal logic.

1.3.1 Seamless System Architecture

1.3.1.1 Element Distribution and Accommodation

It is not sufficient simply to distribute and integrate applications (such as wargames or vehicle simulators). This would lead to an ever-decreasing efficiency and rising costs with the integration of more and more applications. It is necessary to accommodate and distribute at the element level, which includes applications, processes, databases, user interfaces, and users. In other words it is necessary to find the atomic level at which integration should take place [DEC, 1991; Downes-Martin, 1991].

1.3.1.2 Reusability

One purpose of Seamless Simulation is to be able to use the large corpus of extant systems as building blocks to create a flexible and realistic combat simulation system. Seamless Simulation must be able to reuse applications as the requirements of the users change. However, applications that are developed for specific needs are often optimized in such a way that they are either unsuitable for similar problems or too expensive to modify for those similar problems. Thus techniques must be developed for decomposing applications into their reusable components, and designing new systems with reusability in mind [DEC, 1991].

1.3.1.3 Redundancy

Many of the systems interlinked in the Seamless Simulation will contain components of similar functionality, and some of these will be implemented in a similar fashion. Thus there could exist large bodies of redundant code carrying out the same functions for different applications [DEC, 1991]. For example, the same tank may simultaneously exist as a simulator and as part of a force in an aggregated simulation. This may become a serious problem as the Seamless Simulation expands, and the Seamless Simulation must resolve such redundancy in a manner that maintains consistency and coherence. One approach proposed by Loral [Loral, 1990] to accomplishing this is to employ an overarching battleboard [NSC, 1990]. The Element Distribution and Accommodation and Reusability issues discussed above are relevant to this issue.

1.3.1.4 Substitutability

Users must be able to substitute functions and capabilities from the elements available in the Seamless Simulation, rather than have to build new capabilities every time their requirements change. This implies the decomposition of applications, and the ability to locate the relevant components [DEC, 1991].

1.3.1.5 Extensibility

Applications in the Seamless Simulation must be capable of independent extension and modification. This must occur in such a way that the Seamless Simulation remains consistent, and other applications can make use of the new functionality and capability both in run-time and pre-run-time synthetic environment construction [DEC, 1991].

1.3.1.6 Application Integration and Building

In order to construct the synthetic environment of the Seamless Simulation, it may be necessary for applications to use functionality from other applications. This should be possible without having to model the entire other application [DEC, 1991].

1.3.1.7 Portability

"In a distributed environment it is possible to have different implementations of similar functionality. The operational request may be the same but the actual executable code may be different, depending on platform or user interface for example. Extant code for similar functionality elements may have to be altered to run on different platforms, and new systems will have to be designed with portability in mind" [DEC, 1991]. [See also Loral, 1990; BDM, 1990a, 1990b]

1.3.1.8 Security

The Seamless Simulation is likely to be running multiple synthetic environments simultaneously, each at different levels of security classification. Furthermore, each platform may contain multiple applications or data sets each at different levels of security classification and each being used by different synthetic environments. Finally, combinations of applications or data sets may generate different levels of security classification. Security must be available across the multiple heterogeneous platforms of the Seamless Simulation [DEC, 1991].

1.3.1.9 Preference Specification

"Different users (or organizations) in a Seamless Simulation may have specific preferences for platforms, operating systems, and application versions. These preferences must be provided in an auditable fashion" [DEC, 1991].

1.3.1.10 How to Communicate

"Different applications use different communications transports (RPC, TCP/IP, DECnet, for example). Applications must be able to communicate between different applications and platforms using different communication transports," or a single standard communications transport must be imposed for Seamless Simulation [DEC, 1991].

1.3.1.11 What to Communicate

"A problem exists in knowing what to communicate between multiple distributed independently developed applications. Agreement must be reached between the application receiving the information and that transmitting it." The broadcast-only mode of DIS (as exemplified in SIMNET) is a possible approach. A communications protocol for Seamless Simulation is clearly a major requirement [DEC, 1991].

1.3.1.12 Asymmetric Integration

Integration between systems and the Seamless Simulation can occur in three different ways. Input to the system from the Seamless Simulation, output from the system to the Seamless Simulation, and both input and output with the Seamless Simulation. For example, actual equipment used in a field exercise may have different input/output requirements with the field exercise and with the rest of the Seamless Simulation depending on the relationship between the Seamless Simulation and the field exercise [Loral, 1990].

1.3.1.13 Computational Load

Interfacing applications at different levels of resolution will generate computational loads beyond the capabilities of the platforms initially supporting the applications. Techniques must be developed for dealing with this. For example, a vehicle simulation interacting with a unit level simulation will result in the requirement that the unit level simulation is represented as vehicles to provide the vehicle simulation with a credible synthetic environment. It is unlikely that the original vehicle simulation or the original unit level simulation will have the massive computational redundancy built in to support these additional vehicles. Dynamic fidelity simulation [Downes-Martin, 1989a; Brooks et al., 1989] has been suggested as an approach to this problem.

1.3.2 Seamless Data Management

1.3.2.1 Accessibility

"Users must be able to access elements" of the Seamless Simulation (applications, processes, databases, user interfaces, and users) "as required from remote locations. Furthermore, the elements may be incompatible, and require translation into forms understandable to multiple different users" [DEC, 1991].

1.3.2.2 Application Location

"Users must be able to locate elements" in the Seamless Simulation "and make use of them." Locating the elements becomes increasingly hard in an environment which is large, and in which elements may be redundant, similar, relocating with time, or leaving and entering the Seamless Simulation [DEC, 1991].

1.3.2.3 Availability

"Definitions must be shared across multiple platforms" in a Seamless Simulation environment. "These definitions should be replicable and highly available" [DEC, 1991].

1.3.2.4 Data Representation across Networks

"Computer systems architecture directly affects data representation, thus making it difficult for applications across a network to interact and fully share resources" [DEC, 1991].

1.3.2.5 Link to Existing Data Repositories

"In the past distributed data has been dealt with by requiring that all applications use the same repository. This will be costly and time-consuming" to enforce in a large Seamless Simulation environment. Seamless Simulation "must be able to link extant data repositories in a general purpose fashion" [DEC, 1991].

1.3.2.6 Entity Aggregation

Heterogeneous systems interact rationally by agreeing on an interface protocol [Soley, 1990], and by assuming shared knowledge. Note that there is an interesting analogy here with human speech [Guha and Lenat, 1990]. The systems can either agree to interact always at the vehicle level of resolution or at some mutually agreed intermediate level. In either case data must be translated between levels of organizational aggregation, possibly in both directions. Thus dynamic aggregation and deaggregation of simulation objects are required [Downes-Martin, 1991].

1.3.2.7 Physical Environment Granularity

The granularity of the physical environment, e.g., terrain or electromagnetic spectrum sampling, must be matched between Seamless Simulation elements that have different original requirements. For example, the terrain granularity required to support a

vehicle simulation is different than that used by unit level simulations. Furthermore, objects using the same level of granularity for a physical characteristic may have to use the identical representation, such as terrain for vehicles. However, this is not necessarily true for all objects and all physical characteristics. Attempts by the unit level simulation to interpolate must agree with other interpolation attempts across systems and over time [Loral, 1990].

1.3.3 Seamless Human Machine Interaction

1.3.3.1 Behavioral Realism

Each system must perceive the synthetic reality in its own terms. For example, when manned simulators and computer generated forces interact, the manned simulators must perceive two things about the computer generated forces: The computer generated forces must project individual vehicles, since that is what the humans manning the vehicle simulators expect to see in the real world; the computer generated forces must behave in a realistically human fashion, since in the real world the vehicles would be manned by humans. The manned simulators thus expect two things of the synthetic reality: The physical appearance and behavior (kinematics and dynamics) of the artifacts of the synthetic reality must be as they would in the real world; the tactical behavior of the artifacts must appear as though they are driven by human beings.

Computer driven forces should therefore behave in a sufficiently human fashion so that human participants are unable to distinguish between manned and computer driven forces. In fact this is probably unattainable with current or foreseeable technology, though it does provide a goal to aim for and to drive the research. A more realistic goal is to demand that the detectable behavioral differences between computer driven forces and manned forces do not compromise the purpose of the simulation [Downes-Martin, 1989a; Deutsch, 1989; Abrett et al., 1989, 1990a, 1990b].

1.3.3.2 Human Machine Mix

The mix of human operators and automation to represent human decision-makers is a delicate balance given the current state of the art in knowledge based simulation of human behavior. "Too much automation may result in unrealistic behavior and lost traceability. Too little automation risks inundating the human commanders in the Seamless Simulation or in requiring too many human commanders to be cost effective" [Loral, 1990]. As the

scale of simulated battle increases to many tens of thousands of vehicles (or their equivalent units), the number of organizational levels between the top level commander and the vehicle level of execution increases. Either human operators must be inserted vertically throughout the organizational system (thus breaking an original Semi-Automated Forces design principle, which placed the commander only at the top of the organization); or the Semi-Automated Forces between the top level commander and the vehicle level of execution must become fully automated (to avoid overloading the commander) and behaviorally realistic [Downes-Martin, 1989a; Brooks et al., 1989].

1.3.3.3 Cognitive Knowledge Bases

Monumental knowledge bases will be required to support simulation of human-like behavior and the interaction of humans with simulated agents. These knowledge bases will have to be distributed. The Cyc project [Guha and Lenat, 1990] is one activity attempting to construct a general purpose knowledge base of human consensus knowledge in an attempt to overcome the brittleness of conventional knowledge based systems.

1.3.3.4 Cognitive Modelling

Models of cognition will be required to support simulation of human-like behavior and the interaction of humans with simulated agents [Downes-Martin, 1989a; Deutsch, 1989; Abrett et al., 1989, 1990a, 1990b]. The SOAR project [Newell, 1990] is one activity aimed at providing a general model of cognition.

1.3.3.5 Human Machine Communication

Any computer generated force that is expected to behave in a human fashion will have to be able to communicate with humans (receive and transmit information, requests, orders) in natural language, and between themselves in a manner that is interpretable to a natural language form. Otherwise the human commanders and the software driven forces must either be completely separated in the simulated battle, or the human commanders will be faced with the appearance of battlefield participants who do not behave like humans on the most fundamental level of communications. Human-like communications is a requirement, as are knowledge based systems capable of supporting the simulation of human-like communications [MacLaughlin and Shaked, 1989; Abrett et al, 1990b; Meteer, 1990].

1.3.4 Seamless Time Management

"Simulation interactions must respect temporal causality, both internally (self-consistency) and globally with respect to other simulations" [Weatherly et al., 1991] on the Seamless Simulation (providing global consistency in the synthetic environment). Temporal causality occurs at the system level and application level. For example, "ground and air operations function within different time signatures. Air operations may be observed in real time via the air-defense network. Ground operations status is accumulated slowly by bottom up reporting and analysis" [Loral, 1990].

Table 1. Seamless Simulation References by Issue

Seamless Simulation Issue	Reference
Accessibility	DEC, 1991
Application Integration and Building	DEC, 1991
Application Location	DEC, 1991
Asymmetric Integration	Loral, 1990
Availability	DEC, 1991
Behavioral Realism	Downes-Martin, 1989a Deutsch, 1989 Abrett et al., 1989, 1990a, 1990b
Cognitive Knowledge Bases	Guha and Lenat, 1990
Cognitive Modelling	Downes-Martin, 1989a Deutsch, 1989 Abrett et al., 1989, 1990a, 1990b Newell, 1990
Communicate, How to	DEC, 1991
Communicate, What to	DEC, 1991
Computational Load	Downes-Martin, 1989a Brooks et al., 1989
Data Representation across Networks	DEC, 1991
Element Distribution and Accommodation	DEC, 1991 Downes-Martin, 1991
Entity Aggregation	Guha and Lenat, 1990 Downes-Martin, 1991 Soley, 1990
Extensibility	DEC, 1991

(continued)

Table 1 (cont'd)

Seamless Simulation Issue	Reference
Human Machine Communication	MacLaughlin and Shaked, 1989 Abrett et al., 1990b Meteer, 1990
Human Machine Mix	Downes-Martin, 1989a Brooks et al., 1989 Lorai, 1990
Link to Existing Data Reporitories	DEC, 1991
Physical Environment Granularity	Loral, 1990
Portability	Loral, 1990 BDM, 1990a, 1990b DEC, 1991
Preference Specification	DEC, 1991
Redundancy	DEC, 1991 Loral, 1990 NSC, 1990
Reusability	DEC, 1991
Security	DEC, 1991
Substitutability	DEC, 1991
Time Management	Weatherly et al., 1991 Loral, 1990

1.4 CONCLUSIONS

Industry and academia efforts in areas related to Seamless Simulation are extensive but unfocussed. The issues of integrating general functionality defense systems are explicitly lacking from the DARPA/PMTRADE Workshops on Industry/DoD standards for Interoperability of Defense Simulations. The ALSP (Aggregate Level Simulation Protocol) is an effort in this area but is restricting itself to a few select wargames. The business community appears to be addressing the underlying computing and business problems of integrating heterogeneous distributed systems, but this effort is not faced with the temporal problems introduced by combat simulation's competitive nature. Four recommendations are made:

- **Increase DoD Support.** DoD support for Seamless Simulation projects needs to be demonstrated and strengthened to take advantage of current industry and academia efforts related to Seamless Simulation.

- **Extend UCF/IST Standards.** The current DARPA/PMTRADE sponsored workshop on DoD/Industry Standards for the Interoperability of Defense Simulations needs to be extended from the vehicle level to the general defense simulation and system level.
- **Use Modern Software Engineering.** The DoD Seamless Simulation effort should take advantage of modern software engineering and become explicitly object oriented.
- **Integrate DoD Seamless Simulation and Industry OMG Architecture.** The DoD Seamless Simulation effort should be explicitly integrated with the business Object Management Group Architecture effort to integrate heterogeneous business applications in a seamless environment, and take advantage of the related business products in this area.

2.0 PROJECTS RELATED TO SEAMLESS SIMULATION

2.1 VEHICLE LEVEL SIMULATION AT VEHICLE LEVEL RESOLUTION

2.1.1 Simulator Networking (SIMNET)

SIMNET was an advanced research project sponsored by DARPA in partnership with the United States Army. The goal of the program was to develop the technology to build a large-scale network of interactive manned vehicle combat simulators (see Figure 1 above). The project started in 1983 [Gurwitz et al., 1983], and was successfully concluded in 1990, with SIMNET sites at a number of locations in the United States and Europe. The major developers of the technology were Bolt Beranek and Newman, Inc. (BBN), (responsible for the vehicle simulation code, the networks, the Combat Service Support simulations, Data Recording and Analysis technology, the Flying Carpet technology, and the Semi-Automated Forces) and Perceptronics (responsible for fabricating and integrating the vehicle simulation shells and controls, and requirements analysis).

The purpose of the SIMNET technology was to determine the feasibility of applying large-scale networked manned vehicle simulators to low-cost team training at the Combined Arms Battalion level of combat. The concept of selective fidelity was implemented as a cost and time saving measure. First the tasks necessary for team training were identified. Then the visual and aural cues necessary for triggering task behaviors and the level of fidelity required for each were identified. Thus only those capabilities necessary to support specific team training tasks were implemented.

SIMNET integrated manned vehicle simulators, simple Combat Service Support simulations, and Semi-Automated Forces over local and long-haul networks. All interaction is carried out at the vehicle level, with the broadcast of Protocol Data Units (PDUs) that describe individual vehicles.

2.1.2 Battle Force Inport Training (BFIT)

U.S. Navy forces are trained inport using canned scenarios to support such activities as Command Post Exercises, Enhanced Naval Warfare Gaming System

(ENWGS) wargames, shipboard battle exercises, and combined inport training exercises [Tiernan et al., 1990b]. The inport training makes use of onboard and shore computing capabilities. However, the technology used to support these activities is limited in the sense that the scenarios are canned, and that many ships lack the connectivity and compute power to participate. The BFIT/SIMNET project objective was to exploit SIMNET technology to improve U.S. Navy training capabilities by interlinking the Navy training mockups into a SIMNET network, thus adding flexibility and a higher level of interactivity. Two BFIT/SIMNET proof of principle demonstrations were run (December 1989, April 1990) to determine the feasibility of using SIMNET/BFIT to support the Navy requirements for expanded Navy shipboard training systems. These requirements include a vertical expansion involving training all echelons from deck crew to Fleet Commander simultaneously, and linking inport and at sea training. The conclusions of these demonstrations are given in [IST, 1990a; Tiernan et al., 1990a, 1990b; Tiernan and Boner, 1990; Boner et al., 1991]. The BFIT/SIMNET demonstrations included SIMNET ground and air vehicle simulators from Fort Knox and Fort Rucker, and Navy assets at Fleet Combat Training Center Atlantic (FCTCLANT) and onboard the U.S.S. Wasp. The SIMNET protocols were enhanced to handle naval gunfire support. The BFIT/SIMNET demonstrations were exclusively at the vehicle level of interaction.

2.1.3 ODIN

DARPA formulated the project Odin during the Operation Desert Shield/Desert Storm in response to an urgent and compelling need from the U.S. Central Command (CENTCOM) [DARPA, 1990, 1991a]. The need was for innovative C^2 capabilities to be utilized at multiple echelons. Odin combines elements from several proven technologies, including SIMNET. A message handling system, analysis and support tools, and TACNAT/FULCRUM were integrated with a SIMNET flying carpet and mounted on a mobile truck (see Figure 5). Unit level intelligence was translated from FULCRUM into vehicle level templates and inserted into a SIMNET terrain database. These vehicle level icons were then moved across the terrain database to show historical tracks as dictated by the unit tracks from FULCRUM. Semi-Automated Forces software was used to provide vehicle level animation. The goal was to provide the senior commander with a vehicle level view of the battlefield, via the Flying Carpet vehicle simulator, that correlated with the unit level view given by the intelligence picture.

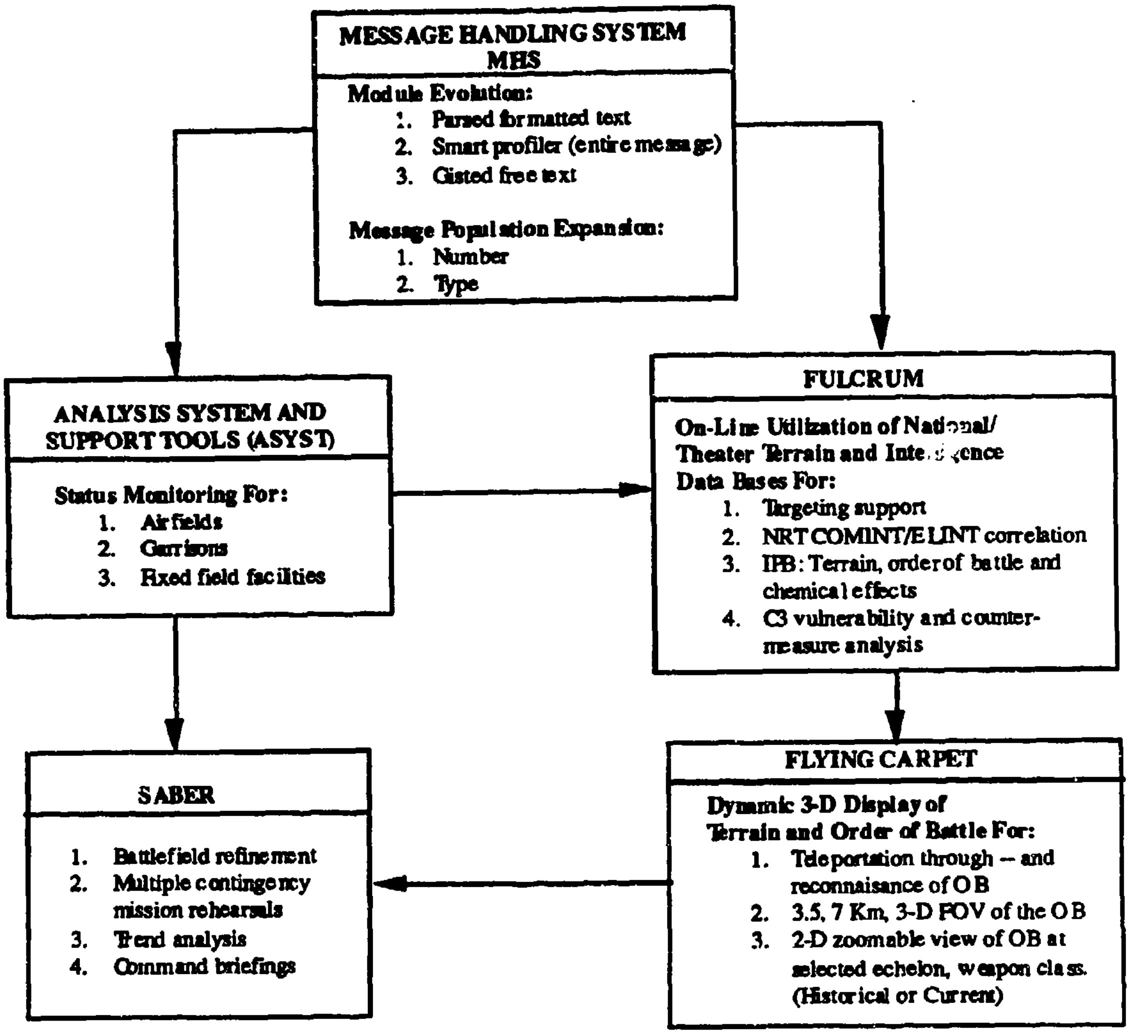

Figure 5: Project Odin. Combines intelligence data bases and analysis, wargames, and message handling technologies with vehicle level SIMNET [DARPA, 1990, 1991a]. All interaction was at the vehicle level, after unit to vehicle level templated translation, so this system does not represent a seamless simulation. However, the linking of these technologies indicates a need which can be satisfied by a full seamless simulation.

2.1.4 Industry Standards for the Interoperability of Defense Simulations

DARPA and PMTRADE are funding an Industry/DoD effort at deriving standards for networking defense simulations. The starting point for these standards is the success of

the SIMNET project. Four workshops have so far been held, all dealing with interaction at the vehicle level. The standards effort is currently broken down into three areas:

- **Communications Protocols Working Group (CPWG).** This working group is now divided into two subgroups, Interface and Time/ Mission Critical (ITMC), and Communications Architecture and Security (CAS). The ITMC subgroup is now concerned with resolving issues related to the draft standard. The CAS subgroup is concerned with defining services and requirements for a communication architecture supporting the DIS application.
- **Simulated Environments Working Group (SEWG).** This is now a reorganization of the former Terrain Databases Working Group. It is now divided into four subgroups: Air, Sea, Land, and Cross-Environments. These subgroups are concerned with issues related to modelling within the specific environments.
- **Performance Measures Working Group (PMWG).** This group focuses on methods for measuring performance of participants in training exercises and weapon systems in developmental test exercises.

Although this effort refers to the "interoperability of defense simulations," it is clear from the proceedings of the four workshops that the draft standards refer to the interoperability of vehicle simulators and simulations (such as SAFOR). Any non-vehicle simulation, such as SAFOR, interacts on the network exclusively at the vehicle level of resolution.

2.2 UNIT LEVEL SIMULATION AT VEHICLE LEVEL RESOLUTION

2.2.1 Knowledge-Based SAFOR

In 1985 DARPA started the Semi-Automated Forces project. The goal of this project was to expand the SIMNET battlefield beyond the battalion team level without prohibitive costs in vehicle simulator hardware and personnel. Instead of each SIMNET vehicle being generated by a single simulator (with several computers) and operated by four crew members, the Semi-Automated Forces would provide a battalion of vehicles generated by a single simulator (of several computers) and operated by a single battalion commander. The crewed SIMNET battalions would thus fight in brigade-regiment-size operations. To be truly effective as a trainer and as a battlefield developments tool, the SAFOR was designed to satisfy a number of principles [Downes-Martin and Saffi; 1987, Downes-Martin, 1990]:

- **Man in the Loop.** The system must be controllable by the human commander, with the consequential presence of human ingenuity and stupidity.
- **A Fight to Win Arena.** Who wins, who lives, and who dies is determined by the skill of the protagonists and the flow of battle, not by umpires, controllers, or computer algorithms. All SAF are ultimately controlled by human intelligence, supported by machine decision and control aids.
- **Fog of War.** The system must not provide the human commander with omniscience or omnipotence.
- **Realistic and Adaptive Behavior.** The SAF must be able to learn from experience as battles progress, and to have their behavior reflect the mixing of green and experienced SAF. Data from human performance analysis is required here.
- **Transparent Box Approach.** The system must not be a black box; instead, it must be capable of being fully validated and modified by the military user community.

The above placed several requirements on the computer generated subordinates of the SAFOR commander; their interaction with the enemy vehicles and with the SAFOR commander was to be as realistic as possible, i.e., as human-like as possible. A knowledge based approach was taken (see Figure 9) [Downes-Martin et al., 1989c; Abrett et al., 1989] to provide the software components with three attributes: human-like behaviors at the vehicle level [Abrett et al., 1990a, 1990b]; a natural language interface to the SAFOR commander [MacLaughlin and Shaked, 1989; Meteer, 1990]; and extensibility for the future without massive hand coding. Since knowledge based technologies cannot currently replace humans, the SAFOR was made to be interruptible by the human commander under emergency conditions [Downes-Martin and Saffi, 1987].

The Knowledge-Based SAFOR was demonstrated in March 1989 in a hands-on exercise of several hundred vehicles distributed in five sites across the United States. The SAFOR commander was able to command at the battalion level, with OPORDS and communications in natural language. Operational reviews of the demonstration indicated that the approach was fundamentally successful, but that the system had to be made more robust and flexible [Cushman et al., 1989]. Technology reviews were held in the Summer of 1989 by DARPA (on the networking and hardware issues) and by IDA (on the knowledge based approach), and determined that the approach was both technologically sound and extensible, but that the system required debugging and hardening [Brooks et al., 1989].

2.2.2 Combat Instruction Set Based SAFOR

In the summer of 1989, DARPA instructed BBN to harden the Semi-Automated Forces for delivery to the field by removing, rather than debugging, all knowledge based technologies. The Combat Instruction Set (CIS) approach was implemented, by which all vehicle and unit behaviors and situations were enumerated bottom up and explicitly coded as finite state machines [Saffi, 1991a, 1991b]. The fight-to-win principle was replaced by a capability giving the SAFOR commander immediate intervention capabilities at all levels of the SAFOR and for all units and vehicles. The SAFOR commander was provided CIS up to the company level, permitting him to command a battalion by explicitly coordinating and synchronizing his companies. The resultant system was more robust and easier to use than the original knowledge based system. A demonstration of the system was successfully held in March 1990 (WAREX 3/90), and reviews indicated that the system was more robust but less flexible [Jacobs et al., 1990; Strand, 1990].

2.2.3 73 Easting

DARPA held a conference 8/26-29 in Washington, D.C., to present the initial results of the 73 Easting project [DARPA, 1991b]. This project is the attempt to capture battle data from the Desert Storm Battle of 73 Easting in SIMNET format and play it back using the SIMNET facilities. A team was sent to the Gulf to interview U.S. participants and survey the battlefield. Individual vehicle locations, movements, fire, and kill events were logged and entered into the SIMNET database. The initial playback using the SIMNET flying carpet was then used to check for consistency and to assist the memories of the original participants as further detail was sought. As was expected, much detail was missing and memories were inconsistent. However, the use of SIMNET in this way was clearly valuable as a debrief tool to extract the maximum information about a battle after the event.

According to BBN and COL Gary Bloedorn at the conference, each vehicle had a data script, drawn from the historical survey, defining its location, movement, firing, and destruction independent of all other vehicle data scripts. The flow of battle was thus obtained by independently choreographing each vehicle. The animation from one data point to the next was carried out using the CIS-based SAFOR, with the CIS logic appropriately suppressed to enforce the required data scripts.

73 Easting indicates another aspect of Seamless Simulation, the requirement (not currently satisfied) to integrate historical data tracks with interactive man-in-the-loop simulation.

2.3 UNIT LEVEL SIMULATION AT UNIT LEVEL RESOLUTION

2.3.1 Aggregate Level Simulation Protocol (ALSP)

In 1984 DARPA first proposed the concept of the Distributed Wargaming System (DWS), which would use and distribute the wargames at the Warrior Preparation Center and provide distributed teleconferencing in support of the Reforger and Warrior Ace exercises [Suter, 1989] for senior commanders. This project is also sometimes referred to as Distributed Wargaming (or Warfighting) Simulation System (DWSS). The use of the combined Warrior Preparation Center (WPC) simulations was partially successful, and the teleconferencing facility extremely so. Ground (GRWSIM), air (AWSIM), intelligence collection, and follow-on forces (FOFA) models were used. Combat resolution between air and ground models was centrally computed. Text reports were generated by each model and distributed to commanders [NSC, 1991a].

This project has now transitioned (functionally) to the Aggregate Level Simulation Protocol (ALSP) project at MITRE, funded by DARPA [Weatherly et al., 1991]. The goal of ALSP is to develop the protocols, by analogy with the SIMNET protocols, for simulated unit-to-unit interaction on a distributed network. This is being done by integrating the ALSP effort is an all-Service working group with technical agency participation. DARPA is on the steering committee with the Defense Modelling Simulation Office (DMSO). An ALSP Specifications document is due in 1992.

MITRE has "prototyped the ALSP by integrating two copies of the Ground Warfare Simulation (GRWSIM) used at the WPC, incorporating the Air Warfare Simulation (AWSIM), and partially incorporating the Corps Battle Simulation (CBS), in preparation for supporting Reforger '92" (see Figure 6). However, there are two versions of the airforce model AWSIM. The official version is held by Blue Flag, but the version that will be used in Reforger 92 is held by WPC. MITRE is working on integrating CBS with the WPC version of AWSIM to support Reforger 92, but the Army wants to integrate CBS with the official Blue Flag version of AWSIM. Attempts are underway to ensure the integration with the WPC version does not deny integration with the Blue Flag version.

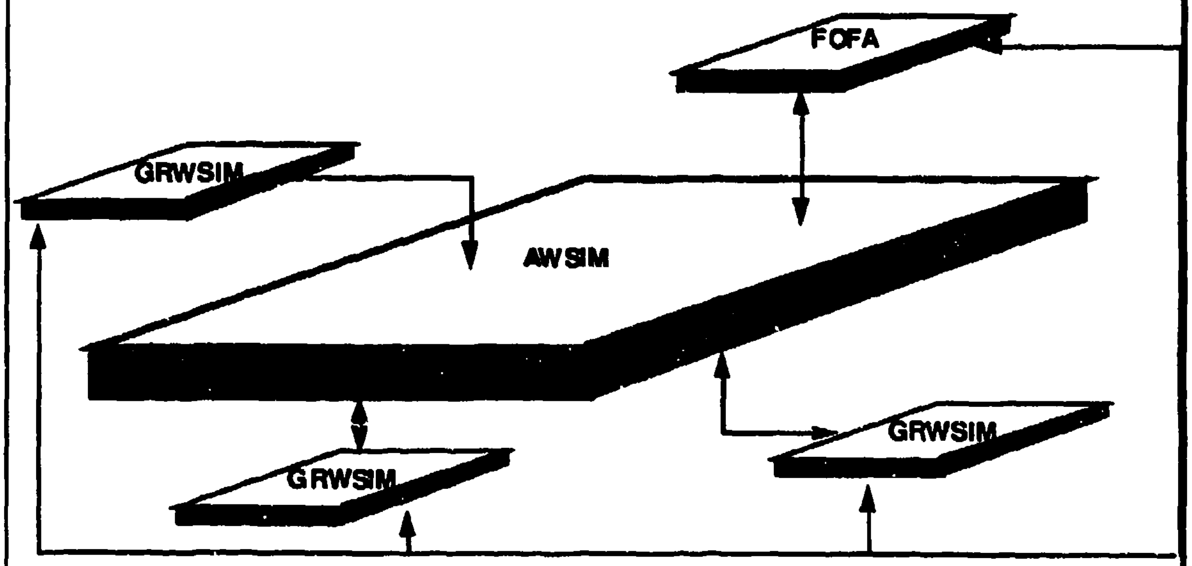

Figure 6: Wargame Integration using ALSP. The ALSP effort currently integrates two copies of ground (GRWSIM) with air (AWSIM) and FOFA [Weatherly, 1991].

2.3.2 Advanced Distributed Simulation Technology (ADST)

In Spring of 1990 DARPA issued the Advanced Distributed Simulation Technology (ADST) RFP. ADST was to be DARPA's simulation effort for the 1990s, building on and leaving behind the undoubted success of the SIMNET technology of the 1980s. This RFP had two funded and one unfunded components. The funded components were a site maintenence and further vehicle simulation development (for rotary wing aircraft). The unfunded component was a complete description of Seamless Simulation. This RFP was withdrawn and responsibility passed to PMTRADE, who reissued the RFP in the fall of 1990, essentially unaltered with Seamless Simulation unfunded and the majority of the funded work being essentially site maintenance and vehicle simulator development. The ADST contract was won by the Loral Team. Meanwhile, DARPA has issued BAA 91-16 which calls for Seamless Simulation research proposals.

PMTRADE has recently announced their BDS-D (Battle Distributed Simulation - Developmental) effort [Pasha, 1991b] proposing Seamless Simulation development. It appears that the BDS-D will be funded as Delivery Orders under the ADST contract. In

addition, PMTRADE has a BAA 91-02 calling for many of the R&D items needed for Seamless Simulation.

2.3.3 Fort Leavenworth Warfighting Simulation Programs

Fort Leavenworth hosts at least three organizations as components of the Battlefield Command Integration Program (BCIP), which appear to support the development of Seamless Simulation [BCIP, 1990]. These are the Battlefield Command Training Program (BCTP), The Future Battle Laboratory (FBL), and the National Simulation Center (NSC). The support for Seamless Simulation is by implication. The BCTP calls for the integration of FAMSIM (Family of Simulations) to provide an integrated and distributed training simulation facility (see Figure 7) using current and future systems by the National Simulation Center [NSC, 1990, 1991c]. The FBL is responsible for handling C^2 system deficiencies, and do so using simulation tools [BCIP, 1990].

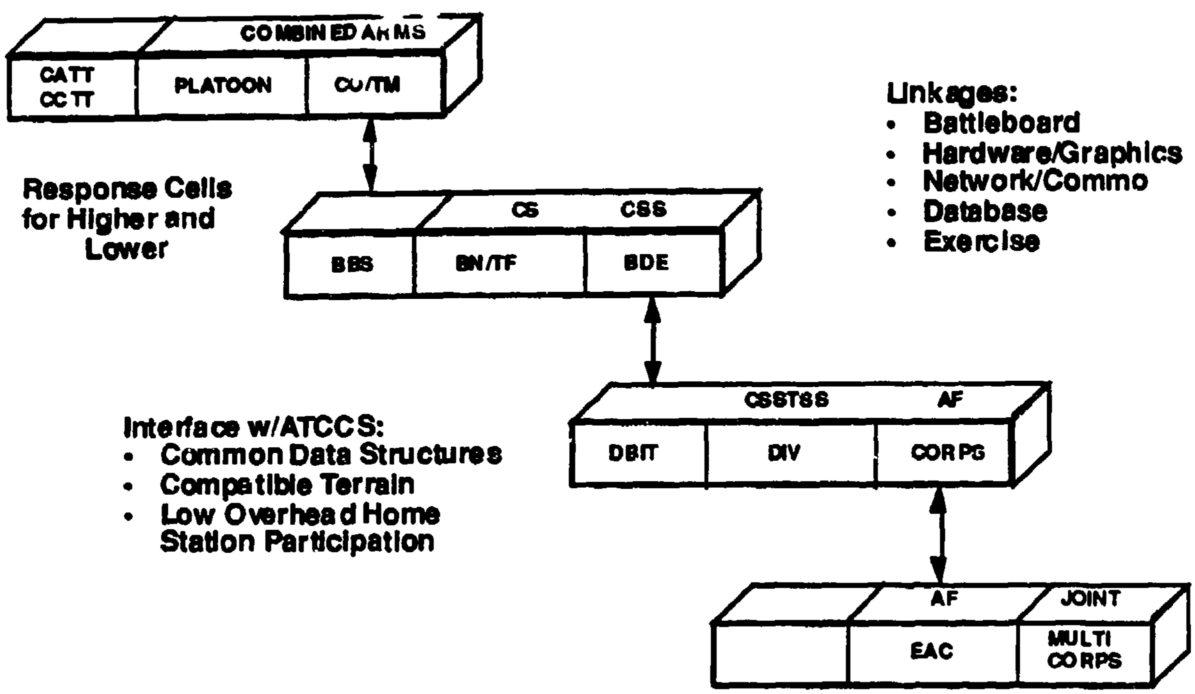

Figure 7: FAMSIM, what we are after. The National Simulation Center calls for integration of training simulations from squad to senior commander [NSC, 1990].

2.3.4 SAFOR Wargamer

The SAFOR Wargamer [Downes-Martin et al., 1989c] was originally developed as the Heuristic Course of Action Evaluator (HCE) for the DARPA/Army ALBM (Air Land Battle Management) project [Abrett et al., 1990c]. The ideas of the HCE were then implemented in the environment of the knowledge based SAFOR, and became a unit level heuristic simulation of the SAFOR running faster than real time. The SAFOR Wargamer was designed to be the planning and evaluation component of the knowledge based SAFOR (see Figure 8), and used the same knowledge representations as did the knowledge based SAFOR (see Figure 9). The SAFOR Wargamer was reviewed by the IDA SAFOR review team on 14 December 1990.

2.4 BUSINESS APPROACHES TO SEAMLESS SYSTEMS

The OMG is an Industry Standards Group attempting to devise standards for the development and use of integrated software systems. They believe that the costs and complexities of future developed systems may best be dealt with by using an object oriented approach. They propose an architecture to provide "...interoperability between applications on different machines in heterogeneous distributed environments and seamlessly interconnects multiple object systems."

They perceive systems to be objects in their own right, and extant non-object oriented systems are integrated by wrapping them with an object oriented interface. A design for the Object Request Broker (ORB) component of the OMG architecture, the message passing facility between heterogeneous systems, has been proposed by two joint teams consisting of DEC/HyperDesk and Sun/HP/NCR/ODI [OMG, 1991].

A number of business products designed explicitly to assist in generating object-oriented wrappers around extant non object-oriented systems for integration with other systems are being announced [DEC, 1991; OMG, 1991], as are other products for implementing the OMG architecture.

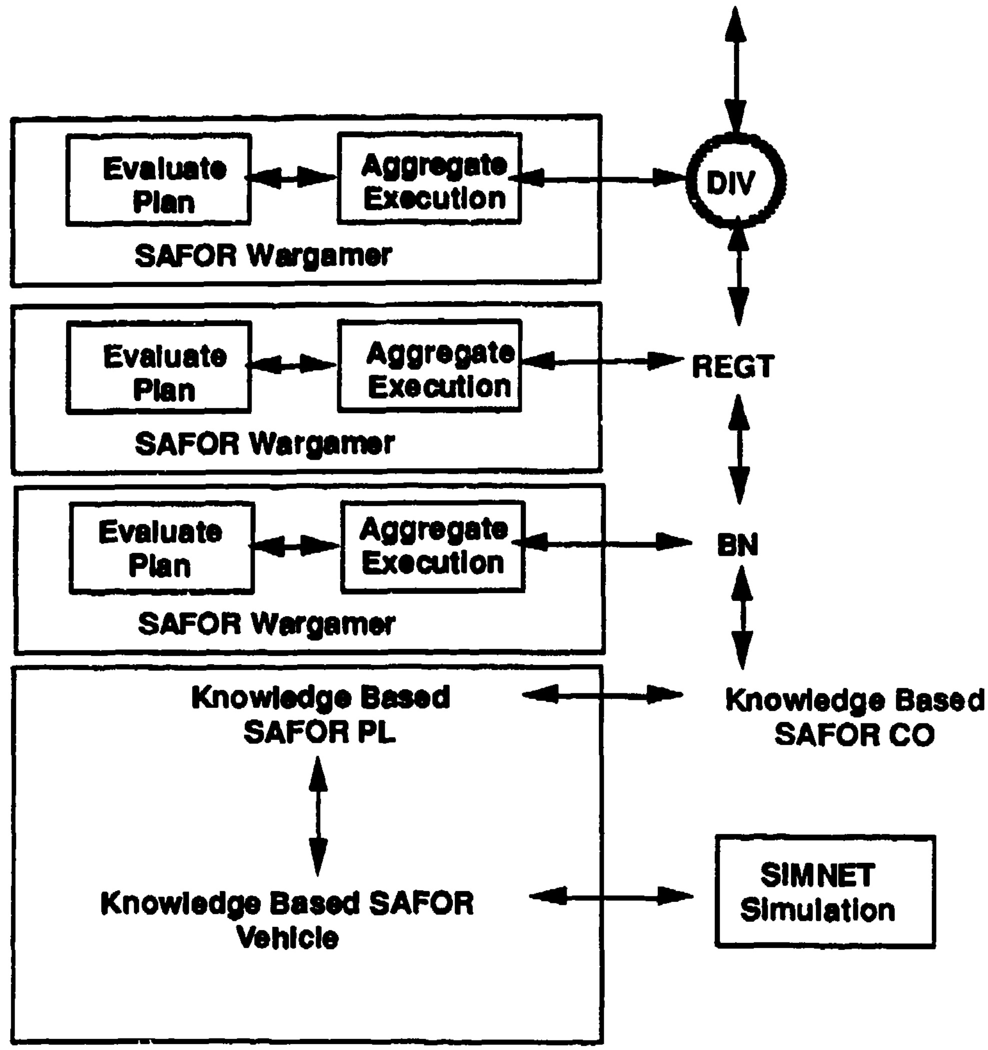

Figure 8: The Knowledge Based SAFOR Wargamer. The SAFOR Wargamer was designed to be integrated with the knowledge based SAFOR at all echelon levels using a unified knowledge representation (IDA Panel Review of the SAFOR Wargamer, 14 December 1990).

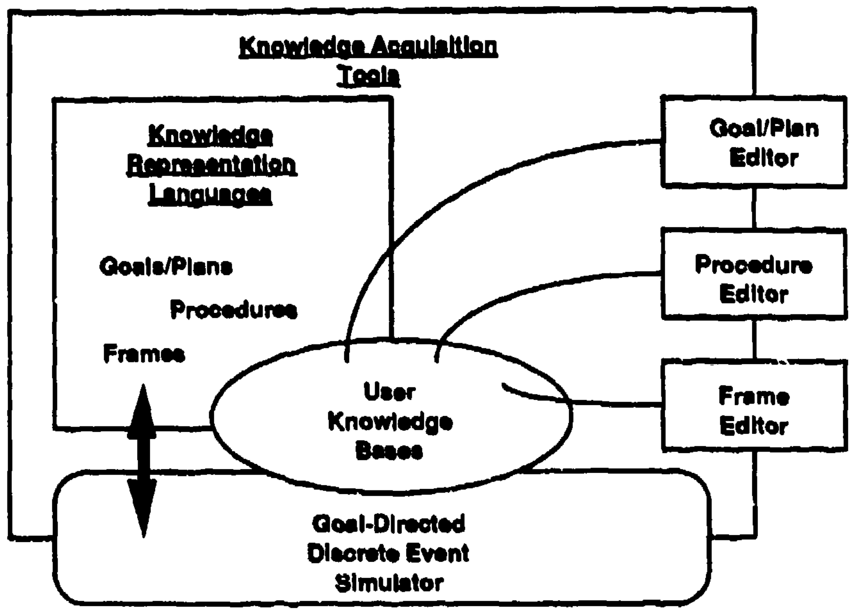

Figure 9: Knowledge Based SAFOR Representation System. An integrated and general purpose knowledge representation approach was used for both the Knowledge Based SAFOR and the SAFOR Wargamer [Downes-Martin et al., 1989c].

Table 2. Seamless Simulation References by Program

Program	References
73 Easting	DARPA, 1991b
ADST	Loral, 1990
ALSP	Suter, 1989 NSC, 1991a Woatherly et al., 1991
BFIT/SIMNET	IST, 1990a Tieman et al., 1990a, 1990b Tieman and Boner, 1990 Boner et al., 1991
CIS Based SAFOR	Saffi, 1991a, 1991b Jacobs et al., 1990 Strand, 1990
Fort Leavenworth	BCIP, 1990 NSC, 1990, 1991c
IST/UCF Interoperability of Defense Simulations Standards	IST, 1990a - h, 1991a, 1991b, 1991d, 1991e
Knowledge Based SAFOR	Abrett et al., 1989, 1990a, 1990b Brooks et al., 1989 Downes-Martin and Saffi, 1987 Downes-Martin, 1990 MacLaughlin and Shaked, 1989 Meteer, 1990 Cushman et al., 1989
Odin	DARPA, 1990, 1991a
OMG Architecture	Soley, 1990 OMG, 1991 DEC, 1991
SAFOR Wargamer	Downes-Martin et al., 1989c Abrett et al., 1990c
SIMNET	Gurwitz et al., 1983 Thorpe, 1987, 1988 Garvey and Monday, 1989

3.0 LITERATURE REVIEW

3.1 DEC, 1991

Application Control Architecture: General Information Guide. Digital Equipment Corporation, 1991.

> Application Control Architecture (ACA) is an object-oriented software technology that facilitates the dynamic linking of independently developed applications across a network. It does so independently of whether the applications being linked were developed in an object-oriented manner. Different applications can be combined like building blocks to provide unique solutions to business problems, especially in fields such as CASE, CAD, CIM, electronic publishing, and decision support. ACA provides a mechanism for building the object-oriented wrappers around extant applications, and then connects them into the Object Management Group Architecture [Soley, 1990] for integration with other heterogeneous applications.

DEC's ACA technology has been developed in the context of the Object Management Group's Architecture [Soley, 1990] for the commercial business world. However, it is clear that the conceptual similarities between this commercial business related project and defense related Seamless Simulation are strong, and so the OMG and ACA projects are discussed here. The analysis carried out by the OMG and its participants (for example DEC) is superior to that found in any of the public domain literature connected with Defense Seamless Simulation. However, the business application world does not appear to deal with the temporal consistency requirements of a Defense Seamless Simulation [Weatherly et al., 1991].

The ACA document discusses the issues facing organizations developing integrated distributed systems today, and how ACA can solve these issues. A detailed view of ACA and its components is provided. The document identifies three requirements for integrating existing technologies with new ones:

- "Existing investments in hardware and software must be supported."
- "Existing and new software applications should be accessible throughout an organization to provide system-to-system interoperability"

- "Existing centralized computing systems at the departmental level should be retained and combined with the advantages of distributed computing environment."

DEC's ACA is an object oriented based architecture for modeling, developing, and integrating business solutions. It deals explicitly with many of the issues discussed in section 1.3.

3.2 DEUTSCH et al., 1991

Deutsch, S., Abrett, G., Pew, R.

The Cognitive Side of Semi-Automated Forces. Proceedings of the Second Behavioral Representation and Computer Generated Forces Symposium: A DARPA Research Initiative. Institute for Simulation and Training, University of Central Florida, May 1991. Mullally, D., Petty, M., Smith, S. (Eds).

This presentation dealt with the cognitive representation and execution of human-like behavior for the Computer Generated Forces. The authors focus on two requirements for Computer Generated Forces, these being the ability to command large organizations and the ability to generate adaptive behavior. The authors describe work in natural language, what-if wargaming, and knowledge representation aimed at satisfying these two requirements.

One of the key issues dealt with in this presentation is the use of simulated communications to command and control the forces and to interface with the human participants. "Operations Orders (OPORDS) and Fragmentary Orders (FRAGOS) must be represented, communicated and executed. In addition, queries and information reports must also be represented and distributed in a simulated communications net." The use of higher level information packets associated with aggregated forces at multiple levels interacting with each other and with manned vehicle simulators will be central to a distributed system of interacting heterogeneous functionality systems. Using a simulation of the communications process between organizations and vehicles can be directly mapped onto the distribution network for DIS.

3.3 DOWNES-MARTIN, 1991

Downes-Martin, S.

The Combinatorics of Vehicle Level Wargaming for Senior Commanders. Proceedings of the Second Behavioral Representation and Computer Generated Forces Symposium: A DARPA Research Initiative. Institute for Simulation and Training, University of Central Florida, May 1991. Mullally, D., Petty, M., Smith, S. (Eds).

> A major goal of both DARPA and the Department of the Army Program Manager for Training Devices for Distributed Interactive Simulation is to extend the synthetic reality of the individual vehicle crew within a combined arms battalion level team to that of the senior commander within a Joint/Theater operation. This requires providing the senior commander with an underlying warfighting simulation which is inspectable at the vehicle level of resolution. To do so involves developing DARPA's concept of Seamless Simulation, in which unit level wargames, manned vehicle simulators and operational equipment can interact in a smooth and seamless fashion. A technical challenge now arises of providing what appears to be a credible and continuous warfighting simulation at the vehicle level across the entire operational area without prohibitive simulation costs in terms of hardware or personnel. An approach is proposed in this paper for giving senior commanders an operation wide warfighting simulation which is inspectable at the vehicle level of resolution without prohibitive simulation costs. This approach exploits the focus of attention explicit in the military hierarchy, in which commanders command one level down and look two levels down. It simulates units at an organizational level of fidelity appropriate to the commander's focus of attention, including down to the vehicle level when the commander is eyeballing the battlefield. Application of this approach has a potentially dramatic and controllable effect on the hardware requirements. However, such an implementation of the vertical and horizontal expansion of distributed simulation technology will also have profound effects on the behavioral representations of the computer generated forces used to interface the human commander with the warfighting simulations.

The focus of attention approach explicitly deals with systems at different levels of granularity interacting with each other over a network, from the human in a manned simulator all the way up to aggregated theater level units. Each level of system is a simulation in its own right, and may very well exist on its own hardware. At the very least, the manned simulator carrying the human commander is a separate piece of hardware from that generating the enemy (and own) aggregated units. Thus this paper deals explicitly with one of the problems associated with Seamless Simulation, that of providing the human participant with a vehicle level view on a large scale simulated battlefield without prohibitive costs, and in doing so clarifies the more general problem of multiple systems at

different levels of granularity interacting in such a way that they each perceive the simulated battlefield in their own terms.

3.4 FISHWICK et al., 1991

Fishwick, P., Petty, M., Mullally, D.

Key Research Directions in Behavioral Representation for Computer Generated Forces. Proceedings of the Second Behavioral Representation and Computer Generated Forces Symposium: A DARPA Research Initiative. Institute for Simulation and Training, University of Central Florida, May 1991. Mullally, D., Petty, M., Smith, S. (Eds).

This paper proposes a detailed definition of the Behavioral Representation problem, and partitions it into key research areas. "The goal of proposing this definition is to provide a common reference point for researchers working on the problem." The key research issues are described as Doctrinal Language Processing, Planning and Intelligent Control, Model Networks, Knowledge Base Representation, Computer Simulation, Animation and Computer Graphics, Autonomous Agent Modeling, System and Network Architecture, Validation, Man-Machine Interface and Software Engineering.

One of the key research areas identified by the authors is System and Network Architecture. In this section the authors comment that the "Computer Generated Forces must interact with other simulation entities via a communications medium." The authors propose a more general level of information flow than that proposed in the IST Standards effort, to include "visual information, radio traffic, auditory or olfactory cues, or information describing physical contact." However, each of these categories appears suitable for individual vehicles or simulated dismounted infantry networked with each other and with manned simulators. It may be possible to consider "radio traffic" to include high level aggregated unit communications. However, it will be necessary to increase the given list to include the network items that will handle the coordination of heterogeneous functionality systems interacting with each other.

Under Model Networks the authors comment on planning and simulation using a variety of models, with the models running at different levels of abstraction depending on whether the simulated object is in view or out of view of a manned simulator. The research issue described is how and when to switch between the different levels of abstraction. This is precisely the point of Seamless Simulation.

3.5 GARVEY, 1990

Garvey, T.

Information Requirements for Unmanned Forces. Position Paper 018-01-90, in Summary Report: The Second Conference on Standards for the Interoperability of Defense Simulations. Volume III: Position Papers. Technical Report IST-CF-90-01, Institute for Simulation and Training, University of Central Florida, January 1990.

Describes the requirements on information exchange between manned simulators and unmanned forces (semi-automated) such that the unmanned forces behave realistically. Assumes that the level of interaction between all forces is at the vehicle level irrespective of whether a manned simulator is in visual range of the unmanned forces.

No issues dealing with unmanned forces at different levels of fidelity (i.e., heterogeneous) were dealt with.

3.6 IST, 1989

State-of-the-Art Assessment for Simulated Forces. Technical Report IST-TR-89-18, Institute for Simulation and Training, University of Central Florida, November 1989.

Summarizes the state of the art in simulated forces as of fall 1989. Provides a review of modeling approaches, problems and achievements, hardware and software, and listings from literature searches. Provides a description of eight major models, and reviews them. Emphasizes object oriented programming as a valuable tool.

Identifies two categories of simulated forces, intelligent simulated forces and battlefield simulations. Intelligent simulated forces deal with the generation of realistic behavior at vehicle to company levels of organization. Battlefield simulation deals with larger units. The report draws the conclusion that the inability to develop a single model that encompasses both categories of simulation appears to be a limitation of the (then) current state of intelligent systems and technology.

The conclusion concerning the lack of integration of battlefield simulations and vehicle level simulations indicates a lack of public domain ideas and work in the area of Seamless Simulation as of November 1989.

3.7 IST, 1990a

Summary Report: The Second Conference on Standards for the Interoperability of Defense Simulations. Volume I: Minutes. Technical Report IST-CF-90-01, Institute for Simulation and Training, University of Central Florida, January 1990.

Section 4.2.1 (Interfacing Simulators) covered an opening presentation by Richard Weatherly of MITRE on distributed wargaming at the Command Post level, specifically at the levels of interest to the Warrior Preparation Center (WPC). Mr. Weatherly broke down the problem into three areas: data semantics, time management, and system architecture. He then discussed the SIMNET (vehicle) level approach to these areas in section 4.2.2 (SIMNET). No proposals or ideas were reported for dealing with Seamless Simulation.

Sections 4.3.1.4 [Battle Force In-Port Training (BFIT)] and 4.3.2.5 (BFIT) discussed the Navy's BFIT project. This project interconnects SIMNET to the Navy's Aegis cruiser mockups. Although at first sight this might seem to be an example of Seamless Simulation, it is not. It still involves functional interactions strictly at the vehicle level.

Section 5.0 (Closing Session) contained the subgroup summaries for the conference. There were no issues raised that dealt with Seamless Simulation.

Although the conference dealt explicitly with vehicle level interactions, and the closing summaries ignored all other levels of interaction, two points during the conference touched on issues relevant to Seamless Simulation. First was Richard Weatherly's discussion of MITRE's work on interfacing simulations at the command level for DARPA [Weatherley et al., 1991]; second, the paper by Sam Knight, "Issues Affecting the Networking of Existing and Multi-Fidelity Simulations."

3.8 IST, 1990d

Rationale Document: Entity Information and Entity Interaction in a Distributed Interactive Simulation. Technical Report IST-PD-90-1, Institute for Simulation and Training, University of Central Florida, June 1990.

See IST, 1991b.

3.9 IST, 1990e

Military Standard (Draft): Entity Information and Entity Interaction in a Distributed Interactive Simulation. Technical Report IST-PD-90-2, Institute for Simulation and Training, University of Central Florida, June 1990.

See IST, 1991b.

3.10 IST, 1990i

A Testbed for Automated Entity Generation in Distributed Interactive Simulation. Technical Report IST-TR-90-15, Institute for Simulation and Training, University of Central Florida, August 1990.

Discusses the Semi-Automated Forces Testbed at the Institute for Simulation and Training as of May 1990. Provides a brief overview of requirements, problems, and state of the art of distributed interactive simulation at the vehicle level of resolution and interaction. Describes the planned capabilities of the testbed.

This report deals explicitly with the exchange of protocol data units (PDUs) between entities, where entities are defined as platforms (or battlefield operating systems). The report explicitly recommends building organizations bottom-up, each organization being built on top of some satisfactory lower organizational level object, with interactions occurring at the vehicle level. Seamless Simulation built on the ideas of this report would require all interactions to take place continuously at the vehicle level.

3.11 IST, 1991a

Military Standard (Draft): Entity Information and Entity Interaction in a Distributed Interactive Simulation. IST-PD-90-2 (Revised), Institute for Simulation and Training, University of Central Florida, January 1991.

See IST, 1991b.

3.12 IST, 1991b

Ratio[illegible] Docum[illegible] Entity Information and Entity Interaction in a Distributed Interactive Simulation. IST-PD-90-1 (Revised), Institute for Simulation and Training, University of Central Florida, February 1991.

These documents define Distributed Interactive Simulation as ". . . an exercise involving the interconnection of a number of simulation devices in which the simulated entities. . . ."

(Simulation) Entity types are defined to be vehicles and objects at the vehicle level of resolution (including groups of "life forms"). An entity can belong to an organization, but military organizations as such are not defined as entities.

It is clear that as of Spring 1991 the intention of the standard (draft) is restricted to vehicle levels of simulation, i.e., homogeneous functionality simulators that are implemented heterogeneously. Seamless Simulation is explicitly excluded from the standard, although this does not mean the standard cannot be extended to include it.

3.13 JOBSON, 1990

Jobson, L.

Semi-Automated Forces Modeling for Aircrew Mission Rehearsal Training. Position Paper 022-01-90, in Summary Report: The Second Conference on Standards for the Interoperability of Defense Simulations. Volume III: Position Papers. Technical Report IST-CF-90-01, Institute for Simulation and Training, University of Central Florida, January 1990.

Describes a need in aircrew mission rehearsal training for a system that can project semi-automated tracks at varying degrees of fidelity (simulation update rate) dependent on the track's relationship with the manned aircrew station. Proposes an architecture that requires a new non-SIMNET network.

The ability to change the simulation fidelity of vehicles depending on tactical state is one solution to the problem of simulating large numbers of vehicles continuously at the vehicle level (known as dynamic fidelity simulation, see Downes-Martin, 1989a).

3.14 KNIGHT, 1990

Knight, S.

Issues Affecting the Networking of Existing and Multi-Fidelity Simulations. Position Paper 004-01-90, in Summary Report: The Second Conference on Standards for the Interoperability of Defense Simulations. Volume III: Position Papers. Technical Report IST-CF-90-01, Institute for Simulation and Training, University of Central Florida, January 1990.

Points out that there will be a problem interconnecting extant and future vehicle level simulations at differing levels of fidelity. Proposes that the network protocol should be expanded to deal with this.

Networking vehicle simulators that are at different levels of fidelity is a special case of Seamless Simulation. However, no analysis of the problem or proposals for its solution were given.

3.15 LEE, 1991

Lee, Hung T.

Multiple Autonomous Combatants: Control and Navigation. Proceedings of the Second Behavioral Representation and Computer Generated Forces Symposium: A DARPA Research Initiative. Institute for Simulation and Training, University of Central Florida, May 1991. Mullally, D., Petty, M., Smith, S. (Eds).

> This presentation describes a
>
> general functional model whose instantiation can be used to simulate a variety of combatants ranging from infantry and tanks, to submarines and sonabouys. Secondly, to model the dynamic behavior of the agent motion, a motor-schema-based approach is illustrated that models the unit's dynamic behavior based on the resolution of elliptical velocity fields selectively applied to an agent, or a group of agents, at any one time. Finally, coordinated group behavior is addressed using the models described above.
>
> A granular representation of terrain to match the level, or granularity, of units, is proposed, as are multi-resolution ellipsoid models for the units themselves. Different models can be used to control each level of unit organization. This provides a possible approach to simulating units at multiple levels of organization depending on the organization level of the units being interacted with.

3.16 LORAL, 1990

Advanced Distributed Simulation Technology. Volume 1 Technical. Loral Systems Company Report TP90-027, October 1990.

This was Loral's winning ADST proposal, and has thus become public domain. PMTRADE's acceptance of the proposal indicates faith in the techniques put forward, and so they are examined here. The components of the proposal relevant to Seamless Simulation are those that deal with Higher HQ Command and Control, SAFOR Technology Enhancement, and Seamless Simulation. The proposal contains a general

analysis of the problems of Seamless Simulation, and on how Seamless Simulation is going to be achieved.

3.16.1 Higher HQ Command and Control

Loral's stated approach to Higher HQ Command and Control is to "use existing C^2 prototype facilities to produce fully functional mockups, for example the Loral Command Center Laboratory (CCL)." Integration with Commands will be achieved by two approaches: first, "interface to the Command's own C^3 facility"; and/or second, "integrate the Command's own wargames at Loral's CCL." Loral proposes using BDM's METRIC V [BDM, 1990a, 1990b] as a top-down, large-scale Joint Training Simulation System (JTSS):

> The proposed methodology involves a new consistent simulation architecture. This will provide multiple levels of object aggregation, real world communications protocols to promote seamless integration of actual and simulated devices, low cost terminals for remote access. Furthermore, it will match communications bandwidth requirements to level of detail requirements.
>
> A loosely coupled, message passing architecture is proposed, for integrating the components of the higher HQ command and control centers, that requires no external interfaces. . . . This is called the Joint Training Simulation System (JTSS). . . . Objects, created top down, perceive the simulated battlefield at the appropriate level of detail. . . . Aggregation and deaggregation is managed by the distributed battleboard which is updated by the most detailed representation. . . . Perception is distinguished from ground truth. . . . The JTSS architecture is used in BDM's METRIC system.

3.16.2 SAFOR Technology Enhancement

Loral proposes four interacting areas of technology enhancement which support Higher HQ Command and Control, and support Seamless Simulation. The first deals with computational interactions. Loral proposes to use selective fidelity to control the computational requirements of simulating large numbers (up to 30,000) of battlefield entities with the associated increase in complexity of function. BDM's METRIC model is proposed as a paradigm due to its capability to support user selected levels of fidelity for each model. It is not clear whether Loral means dynamic selective fidelity, in which the fidelity of the entity varies with tactical state, or whether Loral intends that different fidelity models should be available for selection before the simulation is run.

The second area is Realistic SAFOR Behavioral Interactions. A "hybrid system of heuristics, man-in-the-loop, and Artificial Intelligence techniques" are proposed to support "higher level C^2 in SAFOR." Once again METRIC is proposed as the infrastructure for this hybrid, due to its claimed success in incremental improvement.

> Many of the proposed movement, target selection and firing opportunity heuristics have already been implemented by BDM in the Battalion Combat Model (BCOM), and the Operations descriptors approach used in the Army Corps Battle Analyzer (CORBAN) model are also proposed as a more general top down approach than the SAFOR Combat Instruction Sets. [Saffi, 1991a, 1991b]

The third area is the addition of new Battlefield Operating Systems (BOS). As the scale of the battle is increased, the range of BOS must be widened to support all Battlefield Functional Areas (BFA). Loral proposes "to copy BOS physical representations from existing simulations and simulators."

Finally, the fourth area of technology enhancement is the expansion of SAFOR to higher echelons. As the scale of the simulated battlefield increases, the organizational levels in the military hierarchy must also be simulated. Loral proposes "to merge the BDM developed Operation Descriptors (from CORBAN) to create a top down representation of SAFOR, and to merge these with the bottom up Combat Instruction Set approach of SAFOR [Saffi, 1991a, 1991b] to create a complete representation at all echelon levels."

3.16.3 Seamless Simulation

Loral identifies two critical problems in the Seamless Simulation arena. First is to develop "cost effective mechanisms for linking dissimilar simulations" and second, to develop "a methodology for maintaining global consistency in the resulting world of interacting simulations, simulators, wargames, and operational equipment."

Loral proposes an

> object-oriented approach in which multiple objects can represent the same real-world entity at different levels of detail. All entities are thus automatically SAFOR at the highest level of abstraction, and can be overridden by more detailed representations or by human input as required to create local zones of high reality. The Army term of Battleboard [NSC, 1990] is used to refer to the dynamic framework used to both interface the dissimilar simulations and to represent elements not present in any definitive representation.

The battleboard concept proposed by Loral

> is similar to the DATA-BUS approach used by Syscon at the Joint Warfare Center, but with the added responsibility for maintaining global consistency between the representations and simulations.... The battleboard approach is a loosely coupled message passing hierarchy rather than a tight simulation to simulation linkage. Redundancy which occurs by simply linking extant systems to each other is avoided by embedding object oriented representations of entities from different simulation systems into a global architecture.

Loral proposes to "maintain global consistency between the representations and simulations by a combination of top down C^2 and bottom up execution and distributed decision making in an object-oriented framework." METRIC V is proposed as a paradigm for such a system.

Finally, a new set of standards for interfacing dissimilar simulations in a Seamless Simulation is also proposed based on an open systems approach applied to computer communications (the ISO model) as a starting point. Loral points out that additional layers will be needed.

3.17 McBRIDE et al., 1990

McBride, D., Pullen, M.

BFIT Presentation. Position paper in Summary Report: The Third Conference on Standards for the Interoperability of Defense Simulations. Volume I: Minutes. Technical Report IST-CF-90-13, Institute for Simulation and Training, University of Central Florida, August 1990.

Mentions DARPA's interest in war games, networking them together and to vehicle level simulations using wargaming protocols. A group at MITRE is putting together a straw man as part of the DARPA funded Aggregate Level Simulation Protocol (ALSP) project [Weatherley et al., 1991].

3.18 NSC, 1990

Family of Simulations (FAMSIM) Master Plan. Concept Paper. National Simulation Center, Fort Leavenworth, April 1990

This paper calls for the integration and distribution of extant and future training simulations at all echelons of command, from squad to senior commander (see Figure 7). The mechanism of a common battleboard is proposed as an integration medium, the

battleboard being the distributed database in which "ground" or simulation truth takes place. This master plan, and the information paper [NSC, 1991c] is a call for seamless simulation at the unit level of integration.

3.19 PASHA, 1991a

War Training and C^{4}I ops may be joined. C^{4}I Report, Vol. 6, No. 3, February 4, 1991. Pasha Publications, Inc.

A short news report quoting LTC Mark Pullen (DARPA) at an AFCEA convention.

> The DoD wants to blend combat simulation capabilities into future C^{4}I systems as part of a vast military training program.... This will link allied forces with those in the US in training and in combat. Simulation is seen as the key component of various future technologies associated with C^{4}I.

Seamless Simulation of training and operational equipment embedded in future C^{4}I systems is described. See Weatherley et al., 1991.

3.20 PASHA, 1991b

Son of SIMNET born, named BDS-D. Training Electronics & C^{4}I, Vol. 2, No. 4, February 25, 1991. Pasha Publications, Inc.

An announcement by PMTRADE of the follow-on project to SIMNET, with a funding profile. Proposes "linking government, university and industry sites into a soldier-in-the-loop laboratory simulation of the combined force battlefield." It is believed that PMTRADE will fund BDS-D development under the ADST contract [Loral, 1990; PMTRADE, 1990; Pasha, 1991a], invoking the optional task orders of that contract.

3.21 PAYTON et al., 1990

Payton, D., Keirsey, D., Tseng, D.

Database Requirements for Semi-Automated Forces in SIMNET. Position Paper 019-01-90, in Summary Report: The Second Conference on Standards for the Interoperability of Defense Simulations. Volume III: Position Papers. Technical Report IST-CF-90-01, Institute for Simulation and Training, University of Central Florida, January 1990.

Proposes the concept that SAFOR should be simulated at some group level of organization when not in contact with manned simulators, and comments on the definition of when the SAFOR is in contact with manned simulators.

The ability to move between different organization levels in simulation depending on contact with manned simulators is critical to Seamless Simulation. Unfortunately no proposed solution is given.

3.22 PMTRADE, 1990

Request for Proposal: Advanced Distributed Simulation Technology (ADST). Program Manager for Training Devices, July 1990.

This document contains definitions and requirements for Seamless Simulation. In the statement of work, Seamless Simulation is broken up along two operational dimensions. These are functional [as in SOW Section 3.4.2 (Seamless Simulation) in which different classes of equipments are required to be linked] and operational [as in SOW Section 3.3.2.1 (Higher Headquarters Command and Control) in which different commands are to be supported by requiring their indigenous systems to be integrated] .

This ADST contract is the mechanism by which PMTRADE will fund Seamless Simulation. The definitions contained in this RFP were derived from the original DARPA RFP for ADST released and withdrawn in spring of 1990.

3.23 SOLEY, 1990

Soley, Richard M. (Ed).

Object Management Architecture Guide 1.0. Object Management Group Document 90.9.1, November 1990.

This is the first public document of the Object Management Group (OMG). It describes the goals and purposes of the organization, the structure and procedures of its technical committee, and serves as both a preliminary outline of object technology in general and a reference model for the particular structure being built by the OMG.

The OMG is a serious industry group attempting to devise industry standards for the development and use of integrated software systems. They believe that the costs and complexities of future developed systems may best be dealt with by using an object oriented approach. They propose an architecture to provide "... interoperability between applications on different machines in heterogeneous distributed environments and seamlessly interconnects multiple object systems" (see Figure 10). The OMG perceives systems to be objects in their own right, and integrates extant non-object oriented systems

by wrapping them with an object oriented interface (see Figure 11). The architecture contains four major parts:

- "**The Object Request Broker (ORB).** Enables objects to make and receive requests and responses."
- "**Object Services.** A collection of services with object interfaces that provide basic functions for realizing and maintaining objects."
- "**Common Facilities.** A collection of classes that provide general purpose capabilities."
- "**Application Objects.** Specific to particular end-user applications. Non-object oriented extant systems are wrapped by an object oriented interface to the object request broker."

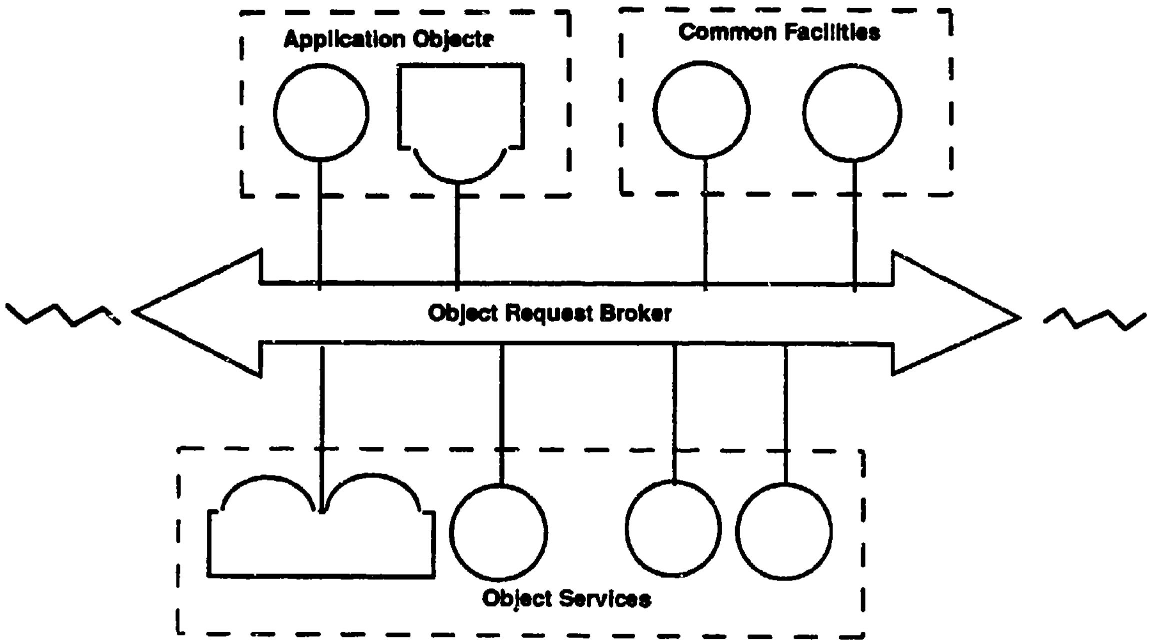

Figure 10: Object Management Group Architecture Overview. The OMG Architecture contains four parts [Soley, 1990]: an Object Request Broker for facilitating communications between objects; Object Services for realizing and maintaining objects; Common Facilities providing general purpose class capabilities; and Application Objects which are particular end-user applications.

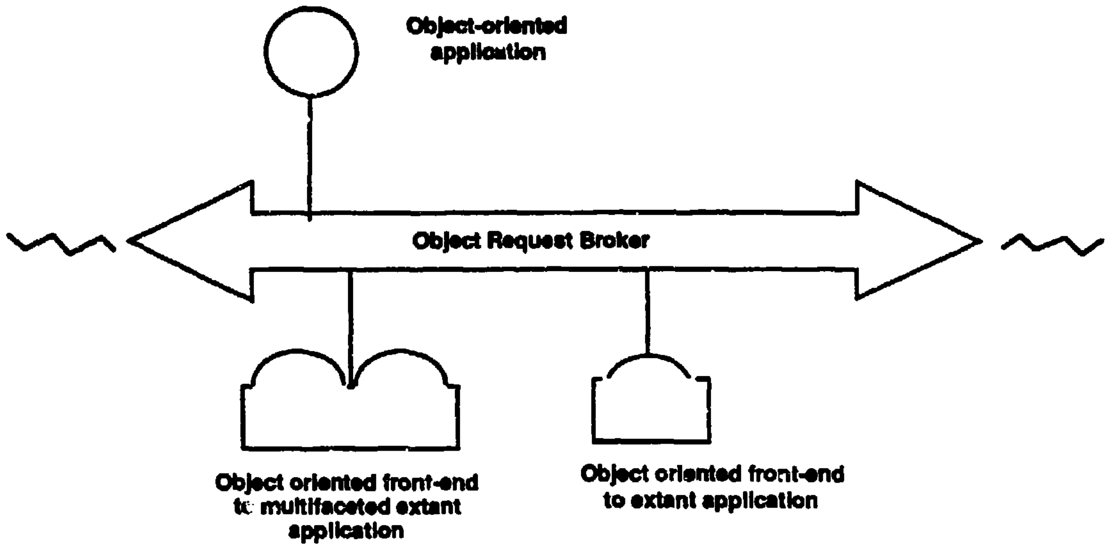

Figure 11: Wrapping Existing Applications. Interfacing general heterogeneous applications within an object oriented paradigm implies the existence of object oriented wrappers as interfaces to extant systems which were not built using an object oriented approach [Soley, 1990; Downes-Martin, 1991].

Business products are already available on the market for OMG applications. For example, DEC's Application Control Architecture [DEC, 1991], an object oriented software technology that facilitates the dynamic linking of independently developed applications across a network.

The OMG Architecture provides a clear and compelling candidate for that aspect of Distributed Interactive Simulation known as Seamless Simulation. Although the purpose of the OMG is to concentrate explicitly on business and civilian applications, the language used is significantly similar to that used to describe Distributed Interactive Simulation (DIS). In OMG Architecture terms, DIS systems such as computer generated forces, wargames, vehicle simulations, and operational equipment are simply Application Objects. Extant DIS systems which are not object oriented would be wrapped in an object oriented interface. The Object Request Broker would be responsible for the communications between the DIS Application Objects. Within each DIS Application Object, processing and communications would remain the responsibility of that object.

It is clear that much common ground exists between the OMG and DIS goals. However, the competitive nature of combat introduces temporal issues into Seamless Simulation not found in the OMG charter.

3.24 TIERNAN et al., 1990

Tiernan, T., Boner, K.

Technology Push Requirements Pull. Position paper in Summary Report: The Third Conference on Standards for the Interoperability of Defense Simulations. Volume I: Minutes. Technical Report IST-CF-90-13, Institute for Simulation and Training, University of Central Florida, August 1990.

The idea of aggregated PDUs for describing groups of ships was discussed during question time.

No analysis of the problem or proposal for implementation.

3.25 WARGO, 1990

Wargo, J.

Distributed Warfighting Simulation. Position paper in Summary Report: The Third Conference on Standards for the Interoperability of Defense Simulations. Volume I: Minutes. Technical Report IST-CF-90-13, Institute for Simulation and Training, University of Central Florida, August 1990.

Defines Seamless Simulation as the "interoperability of all levels of simulators and simulations." Proposes DARPA's Distributed Warfighting Simulation as an example of the first steps in that direction insofar as it integrates Warrior Prep Center games. Also mentions PMTRADE's work linking JESS (Joint Exercise Simulation System) with itself and other simulations.

The first serious mention of technology directed at Seamless Simulation, but no analysis of the problems involved or details of the technology or assessment of the project success.

3.26 WEATHERLEY et al., 1991

Weatherley, R., Seidel, D., Weissman, J., 1991

Aggregate Level Simulation Protocol. Summer Computer Simulation Conference, July 1991.

This paper describes MITRE's work under DARPA funding (LTC Mark Pullen) to develop a protocol for interfacing multiple combat simulations at the unit level. This protocol, known as the Aggregate Levels Simulation Protocol (ALSP), is:

> based on four design principles from SIMNET:
>
> - Distributed computation based on combat entity ownership.
> - Avoidance of single critical resources.
> - Reliance on broadcast communications.
> - Replication of a limited set of combat entity attributes among all simulations.
>
> The ALSP has two peer-level protocols and a vertical connection that joins them. The upper protocol layer is similar to SIMNET in that it deals with interactions between battlefield entities. The lower layer provides simulation time regulation and message transportation services.

It is worth noting the similarity between this approach and that of the Object Management Group Architecture [Soley, 1990]. In the OMG approach the Object Request Broker (ORB), Common Facilities, and Object Services are analogous to the ALSP lower layer.

> [MITRE identifies] three critical challenges: data management, time management, and system architecture. . . . Each simulation object maintains public and private attribute data. Public attribute data is that which is required by other objects in order to interact with each other. Changes to public attribute data is computed and transmitted by the attribute owner. . . . Objects receive the new information, and are responsible for interpreting the information and projecting it into their own private data space. This must be done in such a way that each object perceives the simulation environment in their own terms, and maintains global consistency. . . . This is similar to SIMNET except that now each simulation controls multiple objects, not just a single vehicle.
>
> Temporal causality is achieved by assigning time-stamps based on logical precedence and then executing events in increasing time-stamp order. Local

temporal consistency occurs when each simulation is stand-alone temporally correct. [MITRE proposes to achieve] global temporal consistency by a distributed time management strategy based on the basic Chandy-Misra algorithm [Chandy and Misra, 1979] extended to support a dynamic collection of simulation entities.

[The ALSP architecture] has a three-part, two-layer, application-level protocol component, and a software component (see Figure 12). The software component is in two parts, translators which are added to simulations to permit communication between simulations, and gateways which implement the Chandy-Misra time synchronization algorithms.

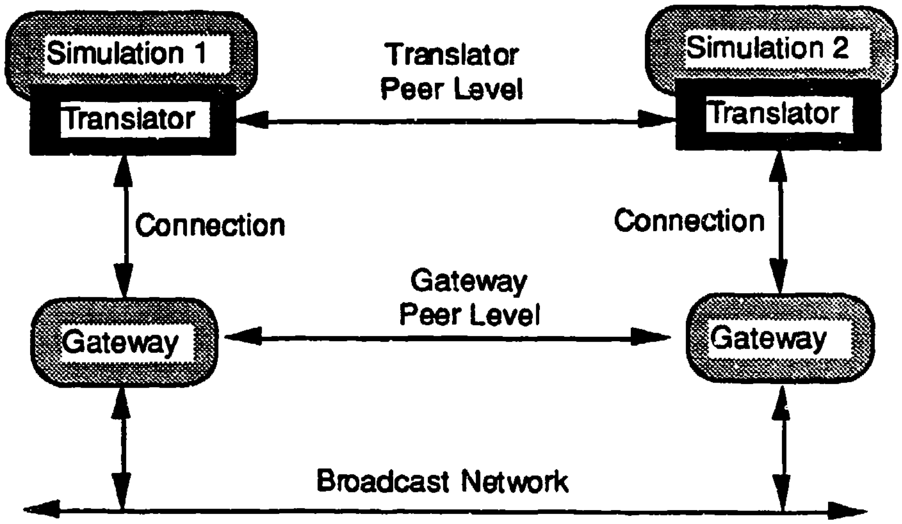

Figure 12: The ALSP Architecture. The ALSP Architecture by MITRE [Weatherly et al., 1991] "has a three-part, two-layer, application-level protocol component, and a software component. The software component is in two parts, translators which are added to simulations to permit communication between simulations, and gateways which implement the Chandy-Misra time synchronization algorithms." Note the analogy with the OMG Architecture of Figures 10 and 11.

MITRE has "prototyped the ALSP by integrating two copies of the Ground Warfare Simulation (GRWSIM) used at the Warrior Preparation Center (WPC), incorporating the Air Warfare Simulation (AWSIM), and partially incorporating the Corps Battle Simulation (CBS), in preparation for supporting Reforger '92." However, there are two versions of the Air Force model AWSIM. The official version is held by Blue Flag, but the version that will be used in Reforger 92 is held by WPC. MITRE is working on integrating CBS with the WPC version of AWSIM to support Reforger 92, but the Army wants to integrate

CBS with the official Blue Flag version of AWSIM. Attempts are underway to ensure the integration with the WPC version does not deny integration with the Blue Flag version.

3.27 YEARICK, 1991

Yearick, P.

Force Level Simulation. Proceedings of the Second Behavioral Representation and Computer Generated Forces Symposium: A DARPA Research Initiative. Institute for Simulation and Training, University of Central Florida, May 1991. Mullally, D., Petty, M., Smith, S. (Eds).

This presentation provides a review of the project history of Force Level Simulation as an Internal Research and Development project at Link Flight Simulation. "Threat environments for man-in-the-loop training have long neglected the importance of modelling Command and Control in attempts to replicate warfare environments for training warfare skills beyond basic 'acquire-aim-fire' logic." Included in the discussion is the objective of the project and what Link viewed as the critical modelling requirements for a Force on Force environment. The progress to date from the initial project conception to recent advancements made in simulating Command and Control structures in real-time simulation is reviewed.

This system makes explicit use of Command, Control and Communications at multiple command levels to tie together the behavior of the objects of the simulation. The existence of multiple levels of command is of particular interest to Seamless Simulation.

4.0 CONCLUSIONS

As can be seen from the necessarily brief literature survey, industry and academia efforts in areas related to Seamless Simulation are extensive but unfocussed. The issues of integrating general functionality defense systems are explicitly lacking from the DARPA/PMTRADE Workshops on Industry/DoD standards for Interoperability of Defense Simulations. The ALSP is an effort in this area but is restricting itself to a few select wargames. The business community appears to be addressing the underlying computing and business problems of integrating heterogeneous distributed systems, but this effort is not faced with the temporal problems introduced by combat simulation's competitive nature. Four recommendations are made:

- **Increase DoD Support.** DoD support for Seamless Simulation projects needs to be demonstrated and strengthened to take advantage of current industry and academia efforts related to Seamless Simulation.
- **Extend UCF/IST Standards.** The current DARPA/PMTRADE sponsored workshop on DoD/Industry Standards for the Interoperability of Defense Simulations needs to be extended from the vehicle level to the general defense simulation and system level.
- **Use Modern Software Engineering.** The DoD Seamless Simulation effort should take advantage of modern software engineering and become explicitly object oriented.
- **Integrate DoD Seamless Simulation and Industry OMG Architecture.** The DoD Seamless Simulation effort should be explicitly integrated with the business Object Management Group Architecture effort to integrate heterogeneous business applications in a seamless environment, and take advantage of the related business products in this area. It is possible for the OMG Architecture to be seriously considered as a candidate paradigm for DIS, and for the work being carried out in the civilian business sector in this area to be exploited by DIS. One approach could be for the University of Central Florida's Institute for Simulation and Training to join the OMG. This would provide a mechanism for inserting DIS requirements into the OMG process, and for the DIS to benefit from civilian business investment in the area.

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Tseng, D.	Hughes Research Laboratories	Payton et al., 1990
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Weissman, J.	MITRE	Weatherly et al., 1991
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	BCIP	BCIP, 1990
	BDM	BDM, 1990a, 1990b
	DARPA	DARPA, 1990, 1991a, 1991b
	DEC	DEC, 1991
	GTRI	GTRI, 1990
	IST/UCF	IST, 1989, 1990a -- j, 1991a -- e
	Loral	Loral, 1990
	NSC	NSC, 1990, 1991a -- c
	OMG	OMG, 1991
	Pasha	Pasha, 1991a, 1991b
	PMTRADE	PMTRADE, 1990

7.0 ORGANIZATIONS

Organization	Address
BBN	Bolt Beranek and Newman, Inc. 10 Moulton Street Cambridge, MA 02138
BCIP	Battle Command Integration Program Command and Control Directorate Combined Arms Command, Combat Developments US Army Combined Arms Command Fort Leavenworth, KS 66027
CAE Link	CAE Link Flight Simulation
Cardinal Point	Cardinal Point, Inc. Afton, VA
CMU	Computer Science Department Carnegie-Mellon University Pittsburgh, PA 15213
DARPA	Defense Advanced Research Projects Agency 3701 North Fairfax Drive Arlington, VA 22203
FBL	Future Battle Laboratory Command and Control Directorate Combined Arms Command, Combat Developments US Army Combined Arms Command Fort Leavenworth, KS 66027
GTRI	Georgia Technology Research Institute School of Industrial and Systems Engineering Atlanta, GA 30332-0205
Hughes Research Laboratories	Hughes Research Laboratories Malibu, CA
IBM	IBM, Federal Sector Division 9500 Godwin Drive Manassas, VA 22110
IDA	Institute for Defense Analyses 1801 N. Beauregard St. Alexandria, VA 22311-1772
IEI	Illusion Engineering, Inc. 2660 Townsgate Road, Suite 530 Westlake Village, CA 91361

Organization	Address
IST/UCF	Institute for Simulation and Training University of Central Florida 12424 Research Parkway, Suite 300 Orlando, FL 32826
Loral/CCTB	Close Combat Test Bed (CCTB) 2021 Black Horse Regiment Avenue, PO Box 89 Fort Knox, KY 40121-0089
Loral	Loral 12443 Research Parkway, Suite 303 Orlando, FL 32826
MCC	Microelectronics and Computer Technology Corp PO Box 200195, 3500 W Balcones Center Drive Austin, TX 78759-6509
MIT	MIT AI Laboratory NE43-822, 545 Technology Square Cambridge, MA 02139
MITRE	MITRE Corporation 7525 Colshire Drive McLean, VA 22102-3481
NCR	NCR Human Interface Center 500 Tech Parkway Atlanta, GA 30316
NOSC	Naval Ocean Systems Center Code 432 San Diego, CA 92152-5000
NSC	National Simulation Center Command and Control Directorate Combined Arms Command, Combat Developments US Army Combined Arms Command Fort Leavenworth, KS 66027
OMG	The Object Management Group 492 Old Connecticut Path Framington, MA 01701
Pasha	Pasha Publications 1401 Wilson Blvd, Suite 900 Arlington, VA 22209
Perceptronics	Perceptronics Inc 21135 Erwin Street, Box 4198 Woodland Hills, CA 91367
PMTRADE	Project Manager for Training Devices Naval Training Systems Center 12350 Research Parkway Orlando, FL 32826-3276

Organization	Address
SRI	SRI International 333 Ravenswood Avenue Menlo Park, CA 94025
TSI	Technical Solutions, Inc. PO Box 1148 Mesilla Park, NM 88047
University of Florida	Dept. of Computer and Information Science University of Florida, Bldg CSE Room 301 Gainesville, FL 32611
University of Pittsburgh	Computer Science Department University of Pittsburgh Pittsburgh, PA 15260, USA
Victory	Victory Integrated Systems 6120 Paseo Del Norte, Suite O-2aa Carlsbad, CA 92008

8.0 ACRONYMS

ABS	Advanced Battle Simulation
ACA	Application Control Architecture
ADST	Advanced Distributed Simulation Technology
AFCEA	Armed Forces Communications and Electronics Association
ALBM	Air Land Battle Management
ALSP	Aggregate Level Simulation Protocol
AWS(S)	Advanced Warfighting Simulation (System)
AWSIM	Air Warfare SIMulation
BCIP	Battle Command Integration Program
BCOM	Battalion COmbat Model
BCTP	Battle Command Training Program
BDS-D	Battlefield Distributed Simulation - Developmental
BFA	Battlefield Functional Area
BFIT	Battle Force Inport Training
BFRS	Battle Force Research Simulator
BFTT	Battle Force Tactical Training
BOS	Battlefield Operating System
C^2	Command and Control
C^3	Command, Control and Communications
C^3I	Command, Control, Communications and Intelligence
C^4I	Command, Control, Communications, Computers and Intelligence
CAD	Computer Aided Design
CAS	Communications Architecture and Security
CASE	Computer Aided Software Engineering
CIM	Computer Integrated Manufacturing
CBS	Corps Battle Simulation
CCL	Command Center Laboratory
CCTT	Combined Combat Tactical Trainer
CENTCOM	U.S. Central Command
CGF	Computer Generated Forces

CIS	Combat Instruction Set
CORBAN	CORps Battle ANalyzer
CPWG	Communications Protocols Working Group
CTLS	Comprehensive Theater Level Simulation
DARPA	Defense Advanced Research Projects Agency
DEC	Digital Equipment Corporation
DIS	Distributed Interactive Simulation
DMSO	Defense Modelling Simulation Office
DTIC	Defense Technical Information Center
DWS(S)	Distributed Warfare Simulation (System)
ENWGS	Enhanced Naval Warfare Gaming System
FAMSIM	FAMily of SIMulators
FBL	Future Battle Laboratory
FCTCLANT	Fleet Combat Training Center Atlantic
FOFA	Follow-on Forces
FRAGO	FRAGmentary Order
GRWSIM	GRound Warfare SIMulation
HSC	Heuristic Course of Action Evaluator
HQ	Head Quarters
IDA	Institute for Defense Analyses
IEW	Intelligence and Electronic Warfare
IFOR	Intelligent FORces
IST	Institute for Simulation and Training, University of Central Florida
ITMC	Interface and Time/Mission Critical
JAWS	Joint Analytical Wargaming System
JESS	Joint Exercise Simulation System
JTSS	Joint Training Simulation System
NSC	National Simulation Center
NTB	National Test Bed
NTIS	National Technical Information Service
OMG	Object Management Group
OPORD	OPerations ORDer
ORB	Object Request Broker
ORS	Operational Reaction System
PDU	Protocol Data Unit

PMTRADE	Program Manager for TRAining DEvices
PMWG	Performance Measures Working Group
RFP	Request for Proposal
R&D	Research and Development
SAF(OR)	Semi-Automated FORces
SEWG	Simulated Environments Working Group
SIMNET	SIMulator NETworking
SPROKET	Simulation PROgramming Knowledge Editing Tool
TARL	Tactical Action Representation Language
TCTS	Tactical Combat Training System
UCF	University of Central Florida
WPC	Warrior Preparation Center

9.0 DATA BASES AND KEY WORDS

The following databases were searched for documents relating to Seamless Simulation:

DTIC

NTIS

and using the Dialog service:

COMPENDEX PLUS

COMPUTER DATABASE

CONFERENCE PAPERS INDEX

SCISEARCH

SUPERTECH

The following key words (with contractions indicated by %) were used to carry out computerized on-line searches of these databases:

%OPERATIONAL REACTION SYSTEM

(%SEMI-AUTO or SEMI %AUTO or COMPUTER GENERATED or COMPUTER-GENERATED or INTELLIGENT) %FORCE

(ADVANCED or DISTRIBUTED or %NETWORK or SEAMLESS or %INTEROPERA or %INTEGRAT or %LINK or HETEROGENOUS) and (%SIMULAT or %WARGAME)

ACCESS

ADST

AGGREGATE LEVEL SIMULATION PROTOCOL

ALSP

AWS

BATTLE COMMAND (INTEGRATION or TRAINING) PROGRAM

BATTLE FORCE INPORT TRAINING

BATTLE FORCE RESEARCH SIMULATOR

BCIP

BCTP

BDS-D

BFIT

BFRS

CASES

CCTT

COMPREHENSIVE THEATER LEVEL SIMULATION

CRONUS

CTLS

DISTRIBUTED WARFIGHTING SIMULATION

DWS

DWSS

EAGLE

FAMSIM

FBL

FUTURE BATTLE %LAB

JAWS

JOINT ANALYTICAL WARGAMING SYSTEM

JOINT TRAINING %SIMULATION

JTSS

METRIC

NATIONAL %SIMULATION CENTER

NATIONAL TEST BED

NSC

ORS

SAFOR

SIMNET

TACTICAL COMBAT TRAINING SYSTEM

TCTS

WARRIOR %PREP CENTER

WPC